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# Technical Assistance Document
# Quality Assurance Guideline for Visible Emission Training Programs

PEDCo Environmental, Inc.
Durham, NC

Prepared for

Environmental Monitoring Systems Lab.
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# TECHNICAL ASSISTANCE DOCUMENT: QUALITY ASSURANCE GUIDELINE FOR VISIBLE EMISSION TRAINING PROGRAMS

by

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This document describes procedures and outlines technical guidance for assistance in establishing effective visible emission observer training programs. Smoke generator operating information is presented and appendices gives examples of sample classroom training lectures as well as audit forms and statistical techniques used to access the quality of a training program. The adherence of visible emissions training programs to the materials in this document should result in improved and consistent levels of observer training. This documentation will aid enforcement programs in demonstrating that the observers were trained without biases and in a professional manner.

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# NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This report provides suggestions and guidelines for persons involved in observer certification and visible emission evaluation and is not a supplement to EPA Reference Method 9. Valid observations can still be made even though all recommendations herein are not completely followed.

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The project was directed at PEDCo by Mr. Carl Nelson, and managed by Ms. Barbara Blagun. The principal editor, Ms. Barbara Blagun, would like to express her appreciation for the invaluable guidance and assistance provided by Dr. John Richards, formerly of PEDCo Environmental, and Messrs. Thomas Logan and Kirk Foster who served as project officers for the U.S. Environmental Protection Agency.

# SECTION 1

# INTRODUCTION

Visual observation of plume opacities is currently the most effective and economical method of determining compliance with opacity-based air pollution control regulations. It is one of the primary enforcement tools used in the United States to determine compliance with particulate emission regulations. The legality and credibility of this method have repeatedly been upheld in court. Recently, however, industry has begun to exercise their rights by challenging the techniques used to read plume opacity. Due to the role of visible emissions (VE) observations in compliance and enforcement of air pollution control laws, it is imperative that personnel conducting these observations make accurate and defensible readings.

Field inspectors and observers are required to document their plume reading skills by periodic participation in a rigorous smoke training and certification program. It is therefore essential that VE observers continue to have the benefit of high-quality training and testing. Accordingly, EPA's Division of Stationary Source Enforcement (DSSE) and the Environmental Monitoring Systems Laboratory (EMSL) have furnished this document to individuals responsible for the general conduct of the VE training and certification program.

# SECTION 2

# ORGANIZATION, PLANNING, AND TRAINING ANNOUNCEMENTS

## 2.1 ORGANIZATION

To ensure a coordinated and consistent program one agency training supervisor should have overall responsibility for the smoke training and certification program. This person will likely need the support of at least two other people, the smoke generator operator and the operator's assistant. The smoke generator operator will be responsible for the preparation, maintenance, calibration, and operation of the generator. His assistant will be responsible for documenting, reading, grading papers, and monitoring trainees. The roles of training supervisor and smoke generator operator could be combined if the classes are held only two or three times a year.

## 2.2 PLANNING

Planning the year's training and certification program is an essential aspect of any successful program. Although the number and frequency of training sessions will be partly determined by past experiences and demands, the school should be scheduled at least twice each year to accommodate persons needing semiannual recertification. Certifying previous graduates while the smoke school is in operation is more efficient and less costly than scheduling a separate session. A summer/winter schedule is generally less desirable than a spring/fall schedule because of adverse weather conditions as well as the need to prepare inspectors for the heavy spring/summer source compliance activities.

## 2.3 TRAINING ANNOUNCEMENTS

Because VE training is an expensive program, it is important to provide a high-quality training program and to have the greatest number of students possible. All local air pollution control agencies within the State or area should be sent in advance a copy of the training schedule, a brief discussion of course content, and a breakdown of the cost per trainee. In addition, industry, trade associations, and journals generally publish such information as a service to their membership. Personnel at major industries and problem sources may be extended a special invitation. Public service notices may be submitted to several newspapers and should include a request for preregistration by interested individuals. Following these steps gives an indication of student load and establishes a point of contact for any followup notices.

## SECTION 3

## CLASSROOM TRAINING

Classroom training program is an essential part of any smoke reading certification program. This training, which is most effectively completed with an intensive 1- or 2-day classroom lecture/discussion session, is beneficial for the following reasons:

1. It increases the visible emission observers' knowledge and confidence for the day-to-day field practice and application.
2. It reduces training time required to achieve certification.
3. It trains the smoke reader to properly record and present evidence that will withstand the rigors of litigation, and greatly strengthens an Agency's compliance and enforcement program.
4. It provides a forum for the periodic exchange of technical ideas and information. For example, periodic refresher courses provide field personnel with updated information and developments, and reinforce good practices and techniques. It can also point out poor techniques and questionable shortcuts that may have become incorporated into routine procedures and operations.

Many States only require classroom training for initial certification. Because the fields of opacity reading technology, legal development, and court decisions develop and change rapidly, however, a full-day refresher course should be given at least once every 3 years as a criterion for certification renewal. Further, the training supervisor should attend one of the instructor seminars offered periodically by EPA because these serve as a forum for discussing and distributing new material, techniques, and training aids.

To assure quality training and optimum student learning, lecturers should be selected with care. They should be experienced, knowledgeable, organized, and have good visual aids and current hand-out materials.

## 3.1 EXAMPLE LECTURE MATERIAL

This section, along with Appendix A, provides only an overview of the classroom session. Separate EPA documents cited in Section 7 should be referred to for further, more detailed guidance concerning lecture materials. The set of lectures included in Appendix A provides samples of material that should be presented as part of the classroom lecture/discussion session. Although these example lectures are not intended to be a model for all schools to follow, the lectures do address most of the important topics covered in a visible emission training program. Thus, this material can be expanded to accommodate changes in the state-of-the-art and can be tailored to needs and regulations of a specific agency.

The following describes a typical, six-lecture classroom training program:

1. Lecture 1 - The student is introduced to the history, principles, and theory of opacity.
2. Lecture 2 - The sources of visible emissions should be presented by experienced enforcement personnel or an engineer thoroughly familiar with source conditions and opacity reading procedures and problems. Note: The use of quality 35-mm slides illustrating common source and plume conditions is recommended during this particular lecture.
3. Lecture 3 - The proper procedures for conducting field inspections are discussed.
4. Lecture 4 - The influence and impact of meteorology on air quality are described.
5. Lecture 5 - The legal aspects of visual emission and opacity measurement should be presented by an attorney familiar with the practices and problems of air pollution control enforcement.
6. Lecture 6 - The actual testing procedures are discussed. This lecture relies upon the foundation built by the previous five lectures.

Appendix A also includes two example quizzes. A short quiz should be given at the conclusion of the classroom series to indicate the trainee's comprehension of the material presented in the lecture and to indicate whether the key points of the lectures have been sufficiently emphasized. If problems arise with specific questions, it indicates that the material has not been clearly presented. It may then be possible to clarify these points immediately or at least to make the appropriate adjustments in subsequent sessions. This provides a QA check on training effectiveness. Two sample quizzes are presented in Appendix A. Note that the last few questions allow a brief critique of the course. These questions will alert the instructor to parts of the lecture that need improvement and thus allow the instructor to constantly improve his presentation.

# SECTION 4

# TRAINING EQUIPMENT

In 1950, the first smoke generator was constructed and used for VE training by the Los Angeles County Air Pollution Control District. The VE training procedures were first outlined by EPA in the Federal Register on December 23, 1971. The most recent standards of performances and specifications for smoke generators were published in the Federal Register, Volume 39, No. 219 on November 12, 1974, as a part of "Method 9 - Visual Determination of the Opacity of Emissions from Stationary Sources" (Appendix 1).

Most Federal, State, and local air pollution control agencies conduct VE training and certification courses at least every six months. This frequency is necessary to maintain opacity reading certification.

This section presents performance specifications and operating procedures for smoke generators that, if followed under a QA program, will ensure nationwide uniformity and consistency with Method 9 criteria. An integrated QA program is particularly important, since VE enforcement procedures are frequently challenged in court and even more importantly, to assure that sources will correctly be observed in either compliance or violation.

An integral part of this program involves the design and operation of the smoke generator in accordance with the requirements of Method 9. In the following sections, the design and operation of the smoke generator and its associated transmissometer are explained, and procedures are given for assuring adequate performance.

## 4.1 METHOD 9 DESIGN AND OPERATING SPECIFICATIONS

Method 9, as published in the Federal Register, contains design and operating specifications for the smoke generator used in the training and certifying of observers. Method 9 was developed by EPA in support of NSPS promulgations. Many states now make reference to Method 9 and even more are moving toward the common use of its operational and design requirements.

### 4.1.1 Smoke Generator Specifications

The procedures to follow in checking compliance with the design specifications are in Section 3.3.2 of Method 9. The specific items to be checked are listed in Table 1. The manufacturer should determine the specifications of the light sources, photocell spectral response, angle of view, and angle of projection. The generator operator is responsible for checking the calibration error, zero and span drift, and response time. Each of these items will be discussed in detail.

TABLE 1. TRANSMISSOMETER DESIGN AND PERFORMANCE SPECIFICATIONS

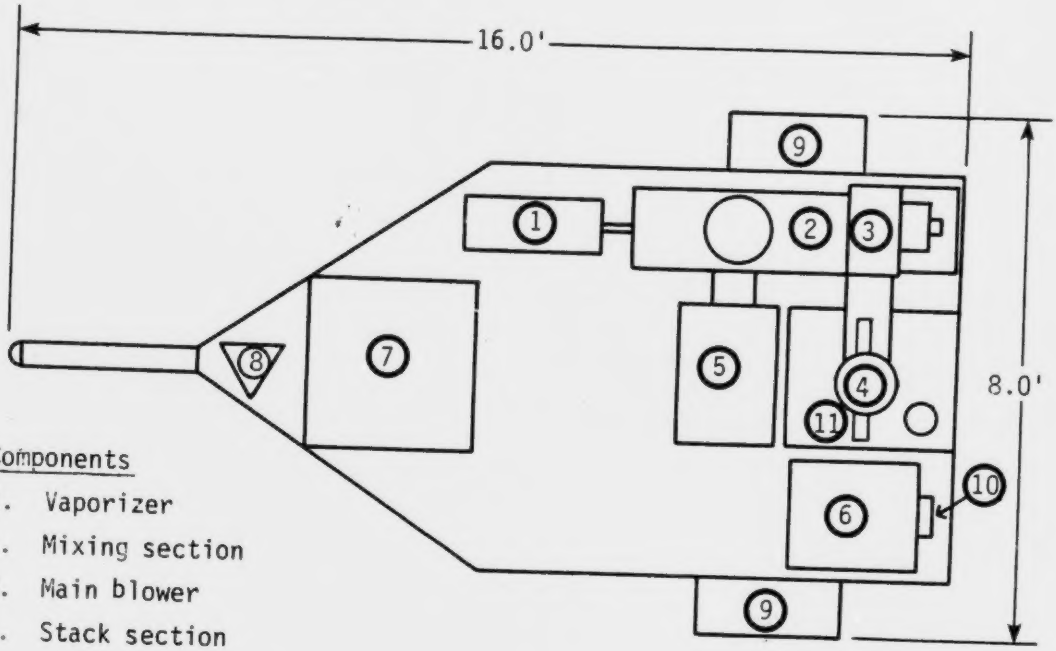
| Parameter | Performance |
|---|---|
| Light source | Incandescent lamp operated at ±5% of nominal rated voltage |
| Photocell spectral response | Photopic (daylight spectral response of the human eye) |
| Angle of view | 15 degrees maximum total angle |
| Angle of projection | 15 degrees maximum total angle |
| Calibration error | ±3% opacity, maximum |
| Zero and span drift | ±1% opacity, 30 min |
| Response time | 5 s, maximum |

## 4.2 SMOKE GENERATOR

The design and operation of the smoke generator have evolved since the mid-1960's. The basic components of a smoke generator include:

1. Black and white smoke generating units
2. Fan and stack
3. Transmissometer system
4. Control panel and strip chart recorder

A schematic layout of an example commercial smoke generator is shown in Figure 1, and a detailed component list is provided in Figure 2. The smoke generator can either be a stationary or mobile unit depending on the training


16.0'
8.0'
9
1
2
3
7
8
5
4
11
10
6
9

Components

1. Vaporizer
2. Mixing section
3. Main blower
4. Stack section
5. Combustion chamber
6. Storage compartment
7. Storage compartment
8. Stack support
9. Fenders
10. Interconnect box to control panel
11. Transmissometer system
12. Remote control panel and strip chart recorder
    a. Strip chart recorder
    b. Digital readout
    c. Transmissometer control
    d. Fuel controls

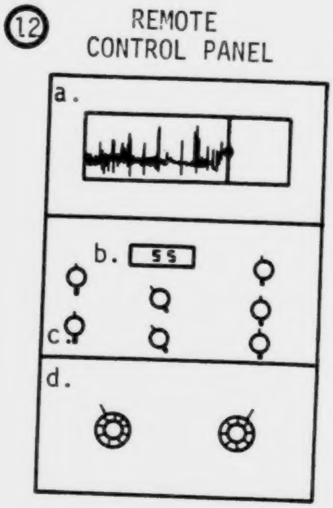

12
REMOTE
CONTROL PANEL
a.
b.
SS
c.
d.

Figure 1. Example schematic layout of a simple generator.

## TRAILER-MOUNTED COMPONENTS

- Trailer hitch
- Storage compartments
- Stack support for transporting
- White smoke vaporizer
- Black smoke combustion chamber
- Ambient air/smoke mixing chamber
- Induced draft (I.D.) fan
- Lower stack section
- Upper stack section
- Hinged support flange
- Transmissometer system (light source and photocell assembly)
- Stack fan
- Main electrical junction box
- Remote fuel line hookup
- Flexible fuel lines
- Electrical interconnect cables
- Solid sheet metal trailer bed
- Trailer axle and brake assembly
- Fuel storage tanks
- Hydraulic system for stack lift

## CONTROL CONSOLE

- Digital opacity meter
- Digital or strip chart opacity recorder
- Main power on/off switch
- I.D. fan control switch
- Stack fan control switch
- Fuel pump control switch
- Light source on/off switch
- Transmissometer span control
- Transmissometer zero control
- Fuel pump selector switch
- Power indicator light
- Toluene fuel control valve
- Fuel oil control valve
- Connects for fuel lines
- Amphenol connectors for electric supply and electronics
- Fuel pumps
- Bell or buzzer
- Speaker system to communicate with trainees

Figure 2. Smoke generator component list.

location. Most units are mounted on trailers, therefore they can be transported to training locations, thereby improving attendance and lowering travel expenditures. The unit should be stored indoors between training exercises in order to lessen weather deterioration and to improve security.

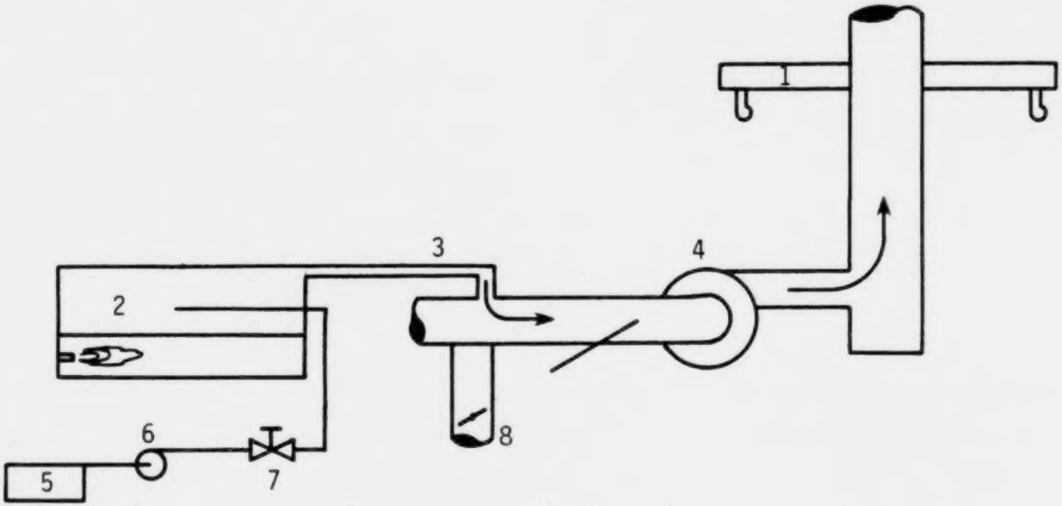
Some negative trade-offs are associated with a mobile unit. It is subject to increased wear due to travel and usually requires additional refurbishment, calibration, and adjustment upon arrival at the training location. Due to these circumstances, the QA issue is of increased importance.

The design and purpose of a smoke generator provide controlled black and white smoke plumes and a means of accurately measuring and recording plume opacity. A smoke generator must be able to generate smoke with an opacity range of 0 to 100 percent and have sufficient accuracy to allow the operator to control and stabilize the opacity of the smoke. Most generators have two basic equipment components: 1) the mechanism that actually produces and controls the smoke and is usually mounted on a trailer for portability and 2) the mechanism that monitors and records the various smoke opacities produced. The use of a separate console for housing the control and recording functions has proven highly desirable because it may be moved away from the generator. The console table also provides a working surface for making notes, reviewing records, etc. The console and trailer unit must have interconnecting lines for the fuels and electronics.

### 4.2.1 Operating Principles

The training, testing, and certification of smoke observers require the use of a device that can produce black and white smoke of any given opacity. The device must be able to achieve and hold opacities in 5 percent increments from 0 to 100 percent opacity. The desired testing opacity must be stabilized at ±2 percent for a minimum of 5 seconds. After the plume is stabilized for 2 or 3 seconds, the bell or buzzer is sounded for the trainee to make a reading. Another 2 to 3 seconds are allowed for the reading. Stability and control are essential and must be checked as part of the QA program.

White smoke is produced by dispensing No. 2 fuel oil into the propane-heated vaporization chamber (Figure 3). After it vaporizes, the vapor is cooled until it condenses into a white aerosol cloud. The opacity of white smoke varies in proportion to the volume of oil vaporized and is regulated



Components

1. Transmissometer
2. Vaporizer
3. Exhaust manifold
4. I.D. fan
5. Fuel oil storage
6. Pump
7. Fuel oil control valve
8. Dilution air damper

Figure 3. White smoke generating equipment.

by adjusting the flow of fuel oil with the fuel oil needle valve located on the fuel control panel.

Black smoke is produced by the incomplete combustion of toluene in the double-wall combustion chamber (Figure 4). The opacity of the black smoke plume is regulated by adjusting the toluene fuel flow controlled by the toluene needle valve located on the console.

Controlling smoke opacity is more of an art than a science because of the many parameters involved, such as fuel quality, temperature, and generator condition. Most operators soon learn their equipment characteristics and become very skilled in regulating plume opacities. This underscores the importance of conducting the smoke school with an experienced team.

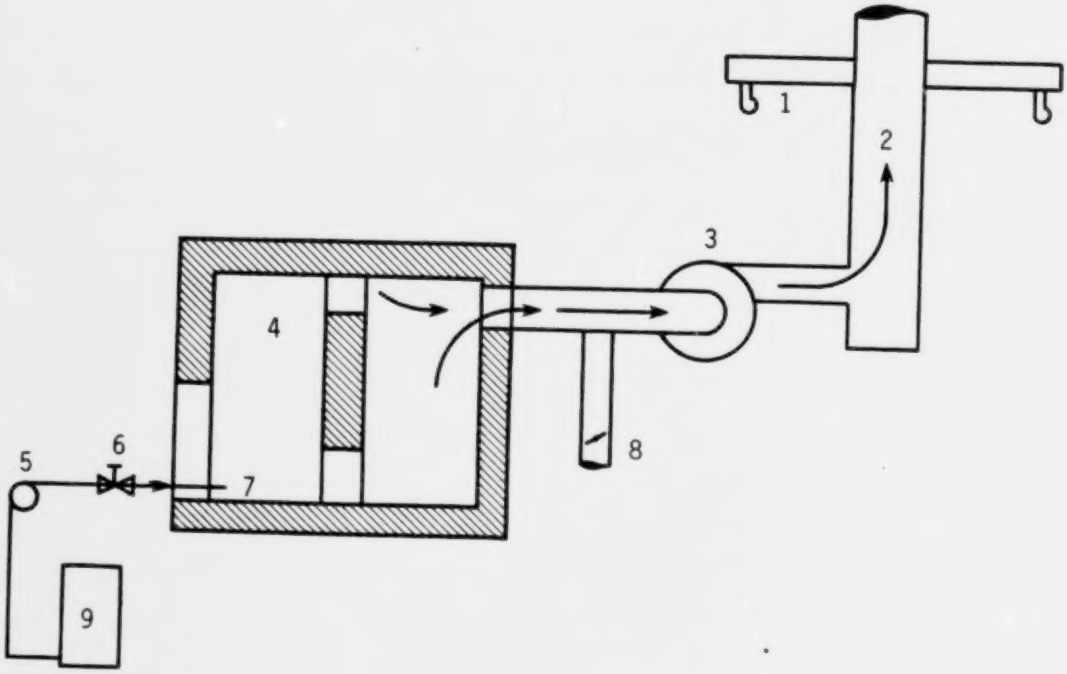
## 4.3 TRANSMISSOMETER

The transmissometer is perhaps the most critical component of the smoke generator, the very heart of the system. Appendix 1 of Method 9 sets forth the specifications for smoke meters or transmissometers (Ref. 3.3.2). An acceptable smoke generator must be in full compliance with these design and operating specifications. The basic smoke generator transmissometer (Figure 5) includes a light source, a photopic photocell detector, and a readout device with a calibrated span of 0 to 100 percent opacity. The light-to-photocell path is approximately 4 ft in length, but only 1 ft, the stack portion of its length, is exposed to smoke. The remaining 3 ft are continually flushed with ambient air from the small fans to prevent smoke buildup and soiling of the lamp or photocell. The transmissometer is located in the 3-in. diameter crossarms of the upper section of the 12-in. diameter stack. The following subsections discuss in detail individual components of the transmissometer and procedures for checking their performance.

### 4.3.1 Calibration Procedures

Before conducting the calibration sequences, the operator should refresh his memory by reviewing Method 9. The transmissometer is calibrated according to this method.

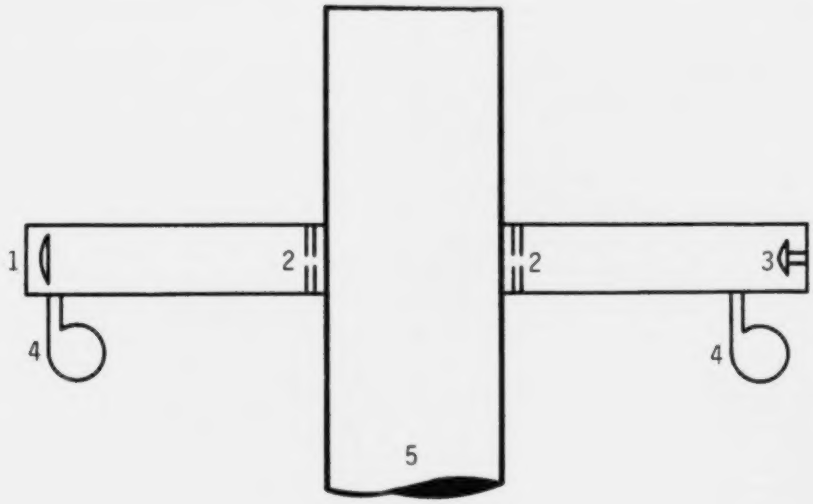
Through field use, the term "calibration" has been expanded from its original meaning in Method 9. When a generator operator refers to "calibrating" the transmissometer, he usually means that a check has been made on



Components

1. Transmissometer
2. Stack
3. I.D. fan
4. Combustion chamber
5. Pump
6. Toluene control valve
7. Nozzle
8. Dilution air damper
9. Toluene storage

Figure 4. Black smoke generating equipment.



Components

1. Light source
2. Smoke stop
3. Photocell
4. Fan
5. Stack

Figure 5. Transmissometer.

calibration error, zero and span drift, and response time of the system, in addition to simply establishing stable 0 to 100 percent readings.

Method 9 specifies that generator transmissometers be calibrated every 6 months or after any modifications or repair to the transmissometer or readout device. Experience has shown that it is strongly recommended that the calibration also be performed before and after each certification course. These calibration checks determine whether any significant drift or deviation has occurred during the certification training period. Since the calibration procedure has been refined to a fairly simple and expedient procedure, these additional checks are not too time consuming and add significantly to overall quality assurance. Keeping in mind the expanded definition of calibration, the following step-by-step procedure should be followed:

1. Allow a 30-minute warmup time for the transmissometer and readout device before starting calibration sequence.

2. Make sure that the light source input voltage is within the ±5 percent nominal rated voltage of the light bulb. This voltage cannot be varied for span purposes.

3. Turn light source to OFF position and establish 100 percent span reference point on readout device.

4. Turn light source to ON position and establish zero span reference point on readout device.

5. Repeat steps 2 and 3 until the 0 and 100 percent span points are established as specified by Method 9. (Refer to Appendix 1 of the Method.)

6. Check for drift of either 0 or 100 percent span points. A maximum of 1 percent over 30 minutes is allowed.

7. Check the response time of the transmissometer readout device with a stopwatch to ensure that it does not exceed 5 seconds. Response time is determined by switching the light to the OFF position and measuring the amount of time until the recorder reaches full scale. A total response time that is too lengthy can cause the transmissometer operator to misread the final value of the opacity reading. Record all response time checks on an appropriate form (Figure 6).

8. Insert three neutral-density (ND) filters into the stack using the calibration wand (Figure 7) to intersect the light beam across the transmissometer cross arm. Take care to prevent erroneous readings from stray light.

RESPONSE TIME CHECK (Method 9, Section 3.3.2.7)

Checked by: ______________________ Date: __________________________

______________________ Time: __________________________

| Check | Response time, sec |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

Time: __________________________

| Check | Response time, sec |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

Figure 6. Example response time check form.

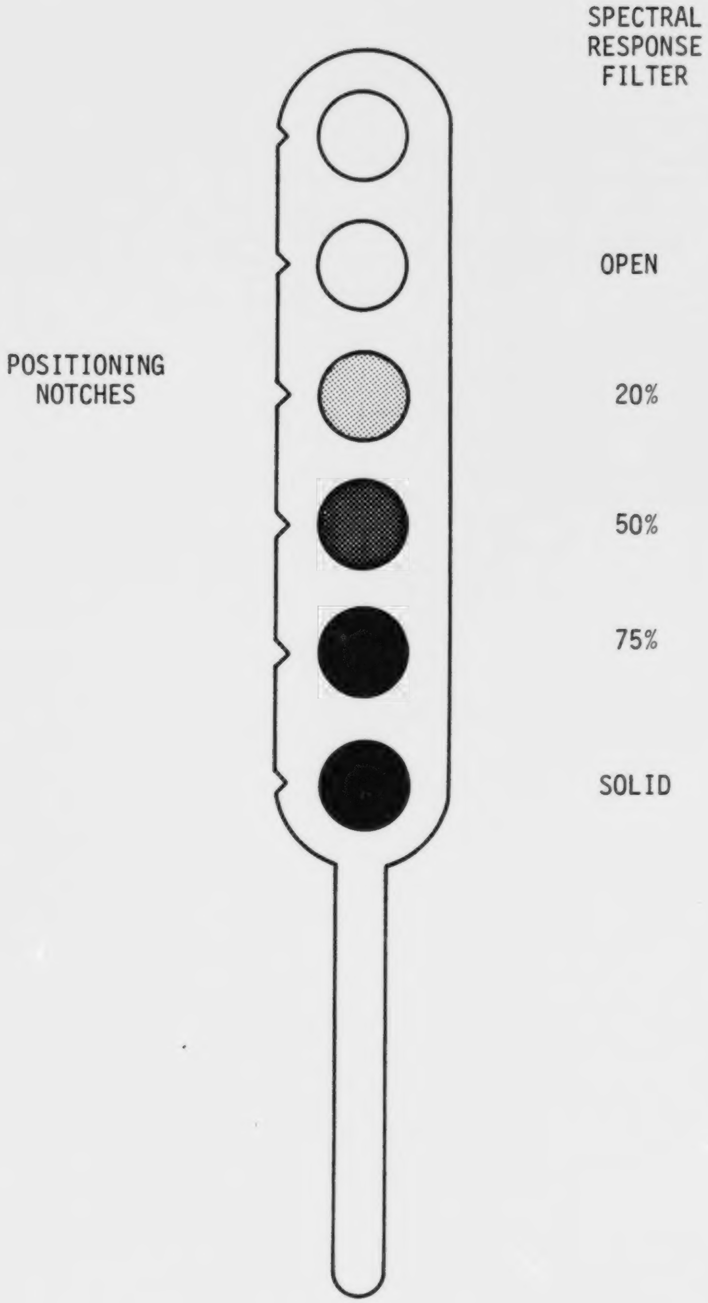

SPECTRAL RESPONSE FILTER
OPEN
POSITIONING NOTCHES
20%
50%
75%
SOLID

Figure 7. Calibration wand.

9. Take five random and nonconsecutive readings for each filter.

10. Record the nominal values of the 20, 50, and 75 percent opacity ND filters on the appropriate transmissometer calibration form (Figure 8). Repeat this step four times, record all values, and graph the calibration error.

11. If any reading exceeds the ±3 percent calibration value for that specific filter, take corrective action before completing the certification test. Check the electrical and readout systems.

12. Have the completed calibration error forms signed by the individual conducting these tests.

13. File all signed documents (Figures 6 and 8) with the VE certification course records for the period in question. This provides the QA element in certifying observer skills necessary to support enforcement litigation.

To ensure a properly calibrated transmissometer, and thus prevent possible legal challenges of calibration accuracy, it is strongly recommended that only glass metallic ND filters that are National Bureau of Standards (NBS)-traceable should be used.

The two most common types of ND filters are composed of gelatin and glass metallic materials. Gelatin filters are fairly inexpensive but may deteriorate rapidly. They inherently have lower quality and greater variation than glass metallic filters. Gelatin ND filters frequently do not meet the Method 9 requirements of ±2 percent accuracy unless calibrated by the more sophisticated spectrophotometers that generally are not available. The glass metallic ND filters, as ordered from the manufacturer, have an NBS calibration curve accurate to ±0.5 percent of their nominal rated values. Calibration curves must be provided with each filter to ensure the exact calibration is at 540 nm on the electromagnetic spectrum. This information should be recorded on the ND filter form shown in Figure 9.

Due to the critical nature of the photocell alignment, no part of the transmissometer system should be removed from the stack assembly during calibration. A few degrees of misalignment can shift readings as much as 5 to 10 percent. Inserting the ND filters into the center of the stack at the transmissometer crossarm eliminates any need for removing either the light source or photocell assembly in order to conduct the calibration. A calibration unit is now available from generator manufacturers or can specifically be built for

CALIBRATION ERROR CHECK (Method 9, Section 3.3.2.5)

Check performed by: ______________________ Date: ____________

______________________ Time: ____________

| Filter | Reading | | | | | Average opacity, % | Maximum error, % | Average reading, % |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | | |
| 1<br>2<br>3 | | | | | | | | |

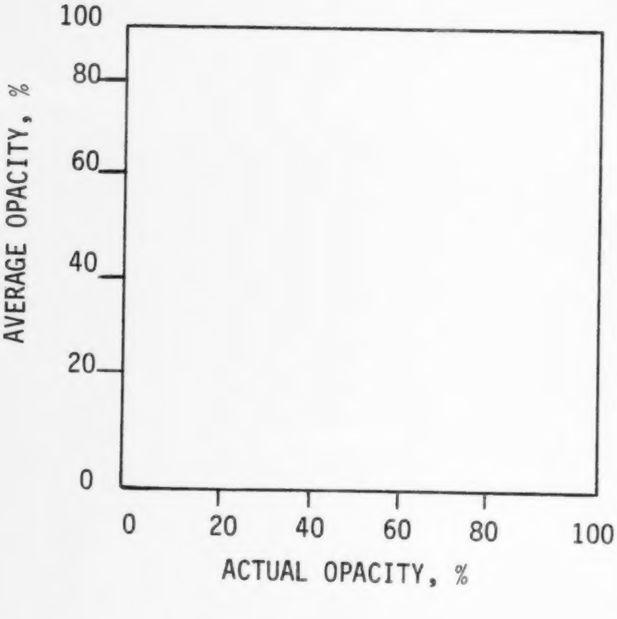


Figure 8. Calibration error check form.

Filters calibrated by: ______________________________

______________________________

______________________________

______________________________

Date calibrated: ______________________________

Were NBS-traceable filters used? yes ________ no ________

| Filter | Nominal opacity, % | Measured opacity, % |
|---|---|---|
| 1 | 20 | |
| 2 | 50 | |
| 3 | 75 | |

Figure 9. Neutral-density filter form.

retrofit on older model smoke generators. Figure 7 illustrates a typical filter holder and calibration wand.

### 4.3.2 Recording Instrument Span

The next step in the calibration process is to set the span of the transmissometer readout device and to measure any drift. Since the transmissometer and recorder are a combination of electronic and mechanical devices, their resultant outputs will display some drift, which is defined as the amount of deviation in percent opacity per unit of time from a given setting.

The following procedure may be followed on a transmissometer and recorder system to check zero and span drift.

1. Warm up the smoke generator/transmissometer system for at least 30 minutes, but do not start generating smoke. This step is needed to allow the system to stabilize sufficiently before the span checks.
2. Turn the light switch to the OFF position.
3. Adjust the output readings (digital and chart recorder) to read 100 percent on the chart scale. This adjustment will be on the readout device and will usually be labeled "zero adjustment."
4. Turn the light switch to the ON position.
5. Adjust the recorder to read 0 percent on the chart scale. This adjustment knob is located on the control panel of newer model generators.
6. Repeat steps 2 through 5 until a stable response is obtained at 0 and 100 percent on the recording instrument scale.
7. Perform the calibration error test.
8. Operate the generator for approximately 1 hour. Repeat steps 2 through 5. The difference between the readings at the start and end of the hour indicates the resulting instrument drift.
9. Record the difference in chart scale for the zero and span on the smoke generator performance data sheet (Figure 10).

This total procedure, which is commonly referred to as a "zero and span" check, must be repeated before and after each test run. If the drift exceeds 1 percent opacity after a typical 30-minutes test run, the instrument must be corrected to 0 and 100 percent of scale before testing is resumed. The drift readings should be recorded in order to develop a historical record of

## Generator Evaluation Data Form

Generator number: ____________________ Manufacturer: ______________________

Operator: ____________________________ Owner: _____________________________

Zero drift, % chart: _________________ Span drift, % chart: _______________

Rise time, sec: ______________________ Fall time, sec: ____________________

Light source lamp voltage, volts: ___________________________________________

### Angle of view (θ) calculation

$\theta = 2 \tan^{-1} d/2L =$ __________ (Note: $\theta$ must not exceed $15^{\circ}$)

where: $L =$ _______mm

$d =$ _______mm

### Calibration Error

| 20 percent | 50 percent | 75 percent |
|---|---|---|
| ____ % chart | ____ % chart | ____ % chart |
| ____ % chart | ____ % chart | ____ % chart |
| ____ % chart | ____ % chart | ____ % chart |
| ____ % chart | ____ % chart | ____ % chart |
| ____ % chart | ____ % chart | ____ % chart |

Tested by: __________________________ Date: ______________________________

Verified by: ________________________ Date: ______________________________

Figure 10. Smoke generator performance evaluation data form.

instrument operation. As a QA measure, this operation log should be thoroughly reviewed at least every 6 months, and it should identify any instrument deterioration or failure so that preventive maintenance can be initiated.

### 4.3.3 Light Source

The smoke generator transmissometer light source in Figure 11 must emit light in a specified visible light spectrum range between 400 and 700 nm. Incandescent lamps are normally satisfactory if operated at ±5 percent of their nominal rated voltage. If an incandescent lamp is operated at a different voltage, though, it will probably emit additional light outside the specified visible spectrum and thereby introduce significant calibration error. A typical light source voltage is determined by the manufacturer and is either listed on the bulb or is available in the manufacturer's catalog. The operating voltage should be measured with an accurate volt/ohmmeter at the base connection of the bulb and verified by the operator. Method 9 requires that all lamps be operated within ±5 percent of their nominal rated voltage. Therefore, a lamp rated at 12 V should be operated only between 11.4 and 12.6 V.

### 4.3.4 Photocell Spectral Response

The most common photocell found in smoke generator transmissometer applications is the selenium photovoltaic-type shown in Figure 12. The photovoltaic series of photocells generate a voltage or current signal proportional to the intensity of light detected by the cell. This voltage is the signal received by the recording and readout components of the control console.

The transmissometer photocell selected for generator applications must have a photopic response range of 400 to 700 nm as specified in the Federal Register, Volume 39, No. 219, November 12, 1974.

The photopic response is generally verified through a careful technical review of the data supplied by the specific generator manufacturer. This includes a check to ensure that a tungsten bulb is being used and that the photocell has the appropriate filters necessary to provide a photopic spectral response output. If the manufacturer's data are insufficient to make an accurate assessment, however, the transmissometer unit should be modified to ensure photopic spectral response.

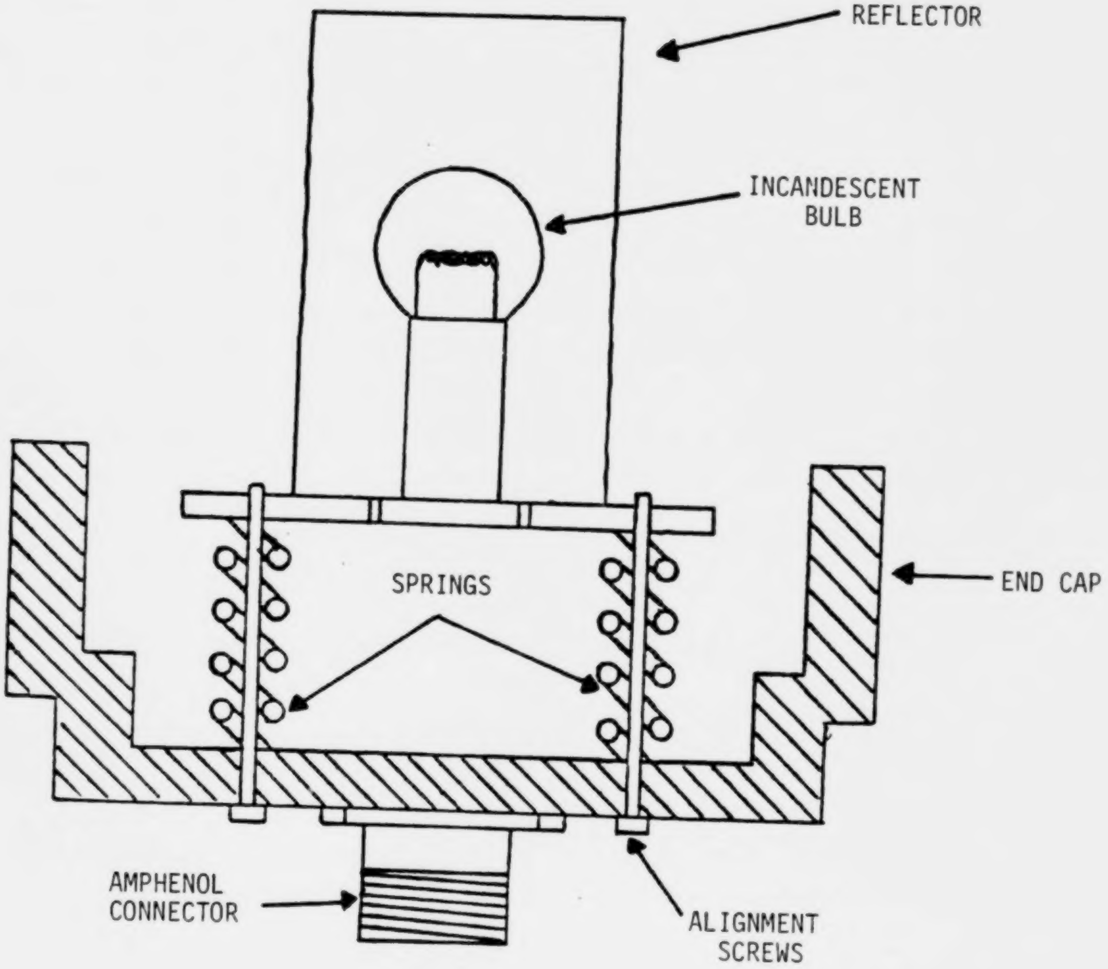
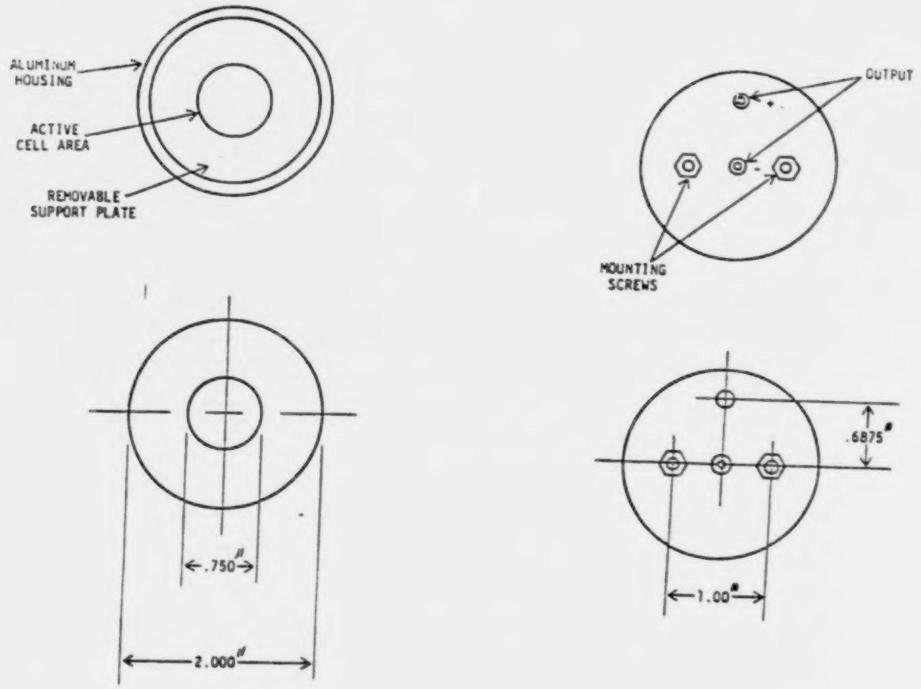
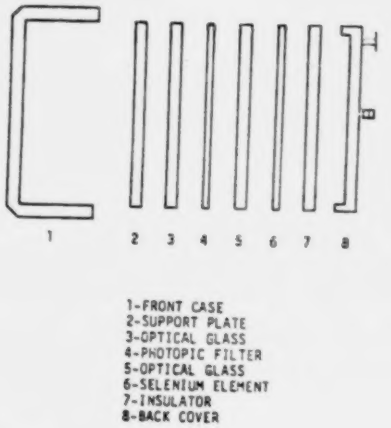

REFLECTOR
INCANDESCENT BULB
SPRINGS
END CAP
AMPHENOL CONNECTOR
ALIGNMENT SCREWS

Figure 11. Example light source.


ALUMINUM HOUSING
ACTIVE CELL AREA
REMOVABLE SUPPORT PLATE
OUTPUT
+
-
MOUNTING SCREWS
.750"
2.000"
.6875"
1.00"

FRONT VIEW

REAR VIEW


1
2
3
4
5
6
7
8
1-FRONT CASE
2-SUPPORT PLATE
3-OPTICAL GLASS
4-PHOTOPIC FILTER
5-OPTICAL GLASS
6-SELENIUM ELEMENT
7-INSULATOR
8-BACK COVER

EXPLODED VIEW

Figure 12. Typical photocell schematic.

### 4.3.5 Response Time

The response time measures the time lapse required for the recorder to change its reading from 0 to 100 percent opacity on the recording instrument following an instantaneous light change in the transmissometer. This time interval should be measured by a stopwatch. Again, this determination should not be attempted until the instrument has been warmed up for at least 30 minutes. The response time allowed by Method 9 is five seconds or less; an ideal response time is between 4 and 5 seconds. Shorter response times can cause the transmissometer readout to fluctuate constantly, making it very difficult to determine precise opacity readings. All response time checks should be recorded on an appropriate form as shown in Figure 6.

The response time is determined by producing a series of five simulated 0 to 100 percent opacity values by switching the light source on and off and observing the time required to move full scale. Note that the generator must not be producing smoke during these checks. The following steps are suggested for checking response time:

1. Warm up the transmissometer/readout system for at least 30 minutes.
2. Span the instrument as described in Subsection 4.3.2.
3. Using a stopwatch, measure the time the recorder takes to move from 0 to 100 percent on the opacity readout device.
4. Make sure that the recorder reads 0 percent with the light source on.
5. Switch the light off and start the stopwatch.
6. Stop the watch when the recorder reaches 100 percent opacity and record the lapse time.
7. Make sure that the recorder stops and stabilizes at 100 percent opacity scale with the light off.
8. Reset the stopwatch, switch light source on, and start the watch. Stop the watch when the recorder reaches 0 percent opacity scale, and record the lapse time.

The transmissometer system response time adjustment is primarily a function of the adjustment of the chart recorder damping. It is recommended that either an electronic technician or the manufacturer make these modifications to the recorder.

### 4.3.6 Angles of Projection and View

The angles of projection and view refer to the projection of light from a light source and the view of this light by the photocell. Light from a given source is projected out in nearly all directions, resulting in highly variable light scattering conditions. The ideal system would have a narrow collimated beam light path. This optimum condition is approximated by limiting the angle of projection to a near-parallel travel band of light waves. Similarly, without shielding to restrict the angle of view, a photocell can respond to incoming light from nearly all angles to its flat face (approximately 180 degrees). Thus, by limiting the angles of projection and viewing to a maximum of 15 degrees, the light scattering errors are minimized over the approximately 1-ft stack diameter.

Limiting the angles of projection and view in a generator transmissometer serves to restrict the photocell's response to those light waves passing through the smoke plume approximately perpendicular to the long axis of the plume. This results in the most accurate measurement of plume opacity.

### 4.3.7 Estimation of Angle of View

The construction geometry should be checked thoroughly to ensure that the total angle of view of the smoke plume, as seen by the photocell, does not exceed 15 degrees. The limiting aperture is the point in the path between the photocell and the smoke plume where the angle of view is most restricted. In smoke generator transmissometers, this is normally an orifice plate. Since correct angle of view usually is established by the manufacturer of the transmissometer, the manufacturer's specifications should be checked prior to performing the measurements and calculations illustrated in this subsection. The total angle of view (V) should then be calculated by use of the following equation:

$$V = 2 \tan^{-1} \frac{d}{2L}$$

where

$d$ = sum of photocell diameter and diameter of limiting aperture, mm
$L$ = distance from photocell to limiting aperture, mm

### 4.3.8 Estimation of Angle of Projection

As is the case with angle of view determination, the general construction geometry should be checked to ensure that the total angle of projection of the lamp on the smoke generator does not exceed 15 degrees. The total angle can be calculated by use of an equation similar to that for angle of view determination (subsection 4.3.7) except for a slight difference in the definition of the parameters.

The total angle of projection (P) should be calculated by use of the following equation:

$$P = 2 \tan^{-1} \frac{d}{2L}$$

where

d = sum of length of lamp filament and diameter of limiting aperture, mm
L = distance from lamp to limiting aperture, mm

The correct angle of projection is established by the manufacture of the transmissometer but should be rechecked by use of the equation in this subsection. Consistent units must be used in the calculations for both angle of view and angle of projection.

### 4.3.9 Stability of Smoke

Method 9 does not specify a time interval during which the generated smoke should remain stable or at a reasonably consistent value. A trained observer should observe the plume momentarily at 15-seconds intervals when making field observations, but trainees may need 2 or 3 seconds to make such determinations. The generator must therefore be capable of holding any set opacity value to ±2 percent for 5 seconds in order to minimize the possibility of incorrect observations.

EPA Region IV, for example, has selected a 2-second observation period for the reader to make the opacity determination. The generator operator signals the beginning and the end of each observation period. Further, Region IV has stipulated two criteria for determining whether the opacity is adequately stable for making a certification reading. These criteria are:

1. The average opacity during the 2-second period is within ±1.5 percent of the intended opacity.

2. The variation of the trace does not exceed 1.0 percent deviation of opacity from its average position at any time during the 2-second period.

Figure 13 illustrates examples of acceptable and unacceptable smoke stability conditions as evaluated by the above criteria.

### 4.3.10 Documentation and Logging for Quality Assurance

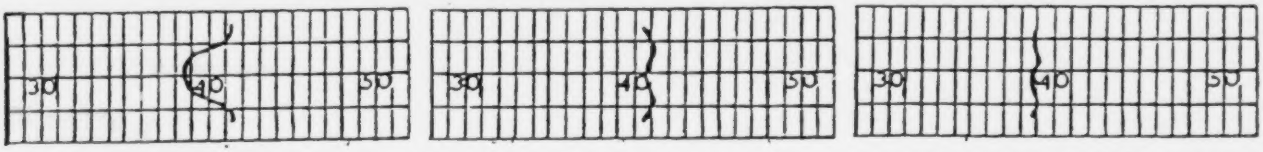
The opacity reading record on field certification activities should be clearly recorded and maintained and is best provided by a continuous strip chart recording showing the actual transmissometer output tracings. This method provides full documentation of the spanning effort and adjustments during the training and certification exercise, and preserves the precise opacity reading conditions for quality assurance. The strip chart also facilitates the marking of each period and observation point for any future comparisons.

As indicated in examples e and f of Figure 13, the generator readout indicates opacity conditions above and below the intended readings. At this point, the generator was producing a very stable plume and the control should have been adjusted slightly to the desired 40 percent opacity. The strip chart recording documents a great deal about the operation of the smoke generator and should be examined for acceptability in the QA review.

All zero, span, mid-range linearity, and calibration filter readings should also be recorded on the strip chart or digital recorder in order to provide a permanent record that these tests were performed and that the Method 9 criteria were achieved for each individual training school. The strip chart or digital recorder should allow the information required through the use of a recommended calibration stamp as shown in Figure 14.

All of the performance verification procedures described in this section should therefore be documented in writing and dated. Some agencies prefer to use a form such as that shown in Figure 10 to record this information, although a bound logbook is highly recommended because it best assures a complete record of all events that concern the performance of the smoke generator, including records of repair and maintenance work, spectral response checks, calibration checks, response time checks, etc. These records are then added to the permanent files of the VE school.

OPACITY LEVELS ACCEPTABLE FOR CERTIFICATION

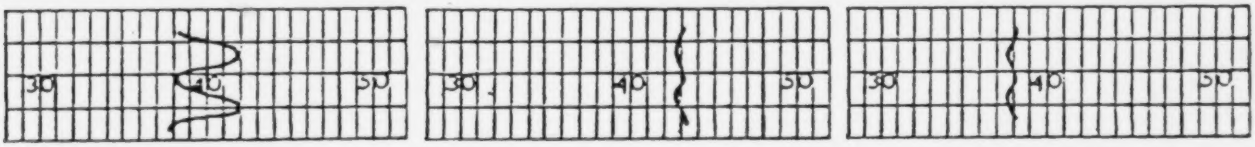


a. variation of <1.5% at 40% opacity

b. variation of <1.5% above 40% opacity

c. variation of <1.5% below 40% opacity

OPACITY LEVELS UNACCEPTABLE FOR CERTIFICATION

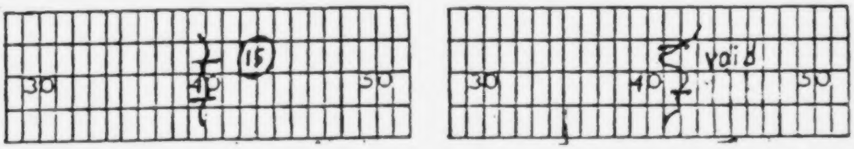


d. variations >1.5% at 40% opacity

e. constant opacity >1.5% above 40% opacity

f. constant opacity >1.5% below 40% opacity

MARKING OPACITY READING PERIODS



g. Valid readings

h. Invalid readings

Figure 13. Examples of acceptable and unacceptable smoke stability conditions.

LOCATION ____________________

DATE ______ RUN ____ TIME ____

1-25 ________ 26-50 ________

GENERATOR ____________________

OPERATOR ____________________

VERIFIED BY ____________________

Figure 14. Recommended calibration stamp.

Proper entries and records can form the data base of an excellent QA program for the school. The records can be used for statistical studies to develop confidence intervals for the training sessions and the individual run forms can be used to develop confidence limits on individual readers.

## 4.4 SETUP, OPERATION, AND SHUTDOWN PROCEDURES

Operating an opacity training and certification program is an expensive but essential endeavor. It is therefore important to minimize the time and effort involved. This is best done by being prepared and thoroughly familiar with the activity.

Since opacity training and certification are not a continuing daily operation, additional preparation is necessary. The smoke generator operator should remove the generator from storage before the training course and run through an operating sequence. This dry run usually identifies minor repair, preventive maintenance, and missing parts or inventory required for assuring high quality and efficient certification runs. Figure 15 provides a checklist of parts and supplies. The following step-by-step operating procedure can be applied to smoke generators to prevent delays and breakdowns during field certification training sessions. The smoke generator operator should practice these steps until a high degree of proficiency is reached. (NOTE: An asterisk (*) indicates that the step must be performed as specified by Method 9.)

1. Assemble and inventory the spare parts and accessories by use of a checklist similar to that shown in Figure 15.

### GENERATOR CHECK

Toluene (2 tanks) ____
Kerosene (1 tank) ____
Funnel ____
Extension/power cord ____
Ground fault interrupter ____
Fuel interconnects (2) ____
Electrical interconnect ____
Propane torch ____
Propane tank (full) ____
Striker ____
Tip for vaporizer ____
Vaporizer ____
Calibration filters ____
Calibration staff ____
Calibration stamp ____
Digital voltmeter ____
Flag and staff ____
Control console ____
Work table ____
Chart paper ____
Pen for recorder ____
Loud speaker system ____
Fire extinguisher ____
Standard operating procedures manual ____

### SPARE PART CHECK

Box fuses 15 A main ____
Box fuses 10 A blower ____
Box fuses 3 A fans ____
Box fuses 1½ A light ____
Box fuses 3/4 A amplifier ____
Torch tip (white smoke) ____
Torch tip igniter ____
Tank "O" rings ____
Valves ____
Bulbs TS67 (12 V) (5) ____
1 k linear pot 10 turn (1) ____
Spare tire (mobile units) ____
Hydraulic jack ____
Disconnects (2) ____
Duct tape ____
Tool kit ____
Lubricating equipment ____

### FIELD FILE CHECK

China marking pens ____
Filter calibration wand ____
Calibration log ____
Roster log ____
Test forms ____
Grading acetates ____
Certification stamp ____
Stamp pad ____
Felt tip pens ____
Extra ballpoint pens ____
Clipboards ____
Large rubber bands ____

Figure 15. Part and supply checklist.

2. Connect the mobile generator and move it to the area of operation. Be sure to select a trailer location that will provide trainees the optimum viewing conditions in respect to background, wind direction, and sun position.

3. Chock trailer wheels and unhitch smoke generator from towing vehicle. Remove towing vehicle to avoid interference with trainee's view of the smoke stack plume. Adjust trailer dolly jack until front of trailer is slightly higher than the rear but level from side-to-side.

4. Check for any damage or evidence of tampering with generator since the last operation.

5. Check fluid level in hydraulic pump, remove the stack securing bracket, and partially raise the stack to resume operation.

6. Lubricate main blower motor. This must be done prior to each certification school by injecting two drops of lubricating oil into each oil cup.

7. Check both the toluene (black smoke) and fuel oil (white smoke) storage tanks to ensure an adequate supply of fuel for the entire certification course. The generator will burn 0.1 gal toluene or fuel oil per certification run; 10 gal of each fuel is adequate for most training and certification sequences.

8. Place the generator's control module with detached console on a table or stand approximately 10 ft from the generator trailer. The control console is normally operated on the left side of the trailer, facing away from the trainees. This position prevents trainees from viewing the transmissometer readout system during certification runs. If the control console is an integral part of the model generator being used, proceed with checking the operability of switches, lights, meters, etc.

9. Make electrical connections by following steps 10 through 15. The electrical connection procedures that apply to the console model of generator are diagrammed in Figure 16.

10. Connect one end of the 16-ft electrical interconnect cable to the main junction box at the rear of the smoke generator trailer, and the other end to the electrical control console. (The interconnect cable connectors are keyed and therefore cannot be connected incorrectly.)

11. Attach the console AC power (117 VAC) cord to the read control panels (3 pin amphenol; refer to Figure 17). Do not plug into AC source at this time.

12. Turn all switches on electrical control console to the OFF position.

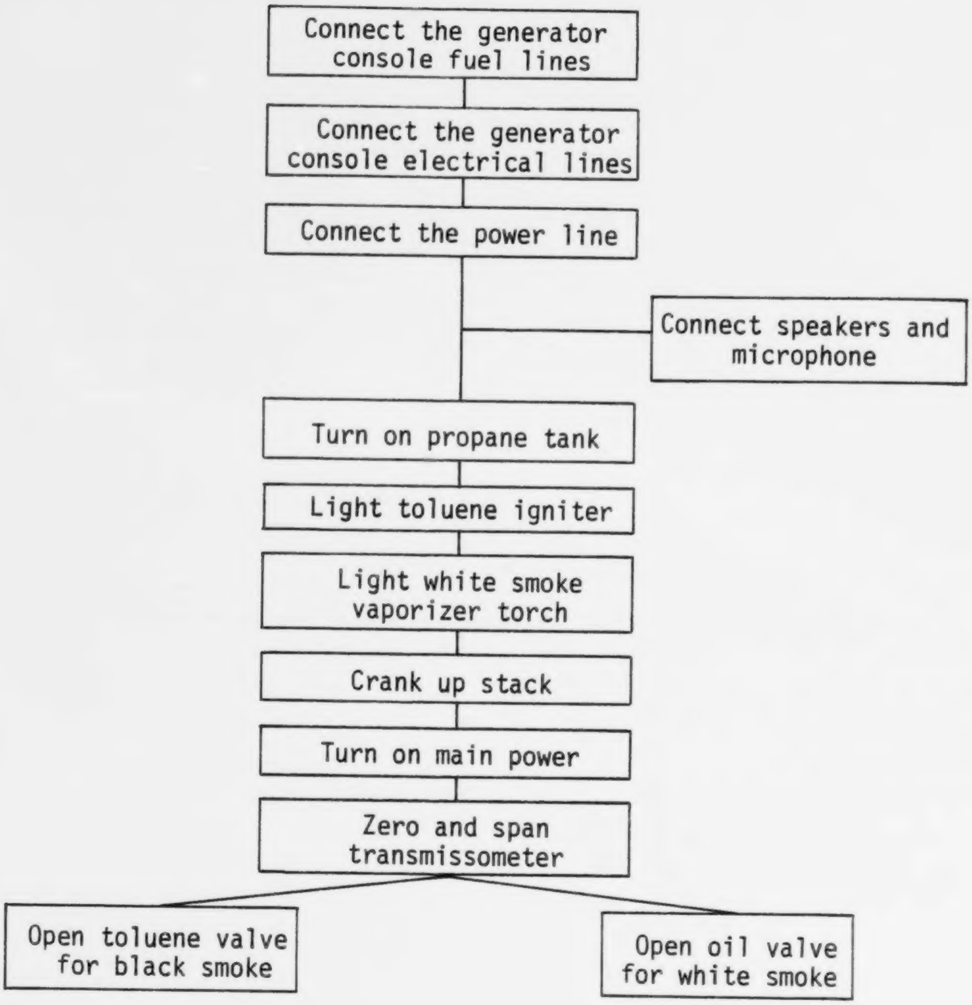
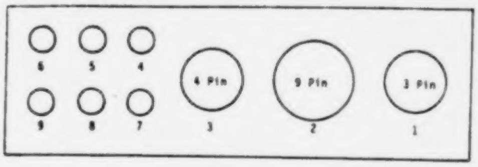
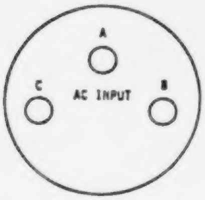

Connect the generator console fuel lines
Connect the generator console electrical lines
Connect the power line
Connect speakers and microphone
Turn on propane tank
Light toluene igniter
Light white smoke vaporizer torch
Crank up stack
Turn on main power
Zero and span transmissometer
Open toluene valve for black smoke
Open oil valve for white smoke

Figure 16. Example generator operation procedure.



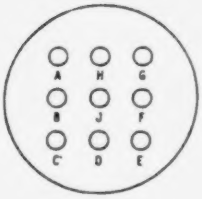
1 - AC Input
2 - Main Output
3 - Photocell Light Source
4 - Fuse Light Source
5 - Digital Readout 12V DC (-)
6 - Digital Readout 12V DC (+)
7 - Fuel Pumps 12V DC (-)
8 - Fuel Pumps 12V DC (+)
9 - Fuel Pumps 12V DC (+)

PANEL IDENTIFICATION



| PIN | WIRE COLOR | VOLTAGE |
|---|---|---|
| A | Red | 117 V AC (-) |
| B | Black | 117 V AC (+) |
| C | Green | Earth-Ground |

3-PIN CONSOLE CONNECTOR



| PIN # | SYSTEM | WIRE COLOR | VOLTAGE |
|---|---|---|---|
| A | Horn | Green | 12V DC (-) |
| B | Stack Fans | Black | 117V AC (+) |
| C | Main blower | Red | 117V AC (-) |
| D | Main Blower | Black | 117V AC (+) |
| E | System Ground | Green | Earth-Ground |
| F | Horn | Blue | 12V AC (+) |
| G | Fuel Pump | Black | 12V DC (+) |
| H | Fuel Pump | Black | 12V DC (+) |
| J | Fuel Pump | Blue | 12V DC (-) |

9-PIN CONSOLE CONNECTOR

Figure 17. Electronic panel of smoke generator control console.

13. Close both fuel control valves. This will generally be in the clockwise direction.

14. The control console normally requires an extension cord to reach the AC power source. The extension cord should be at least 3 wire, 14 gauge, and weatherproof. Plug the control console into a 20 A, 117 VAC, 60 Hz electrical circuit.

15. Set up and test the PA system by connecting the components (microphone, speakers, etc.) in their proper places.

16. Identify and connect the fuel line. Two fuel line interconnect assemblies are included with the generator. The shorter set of fuel lines (10 ft) is connected between the fuel control panel and the fuel shortage tanks. The longer fuel line assembly (16 ft) is connected between the fuel control panel and the fuel input connectors on the rear of the trailer.

17. Connect the fuel lines to the proper input and output connectors on the rear of the fuel control section of the control console. On newer generators, the ends of the fuel lines will be color coded.

18. Open the vents on both fuel storage tanks to allow proper fuel flow through the fuel pumps and to the generator.

19. Connect the long set of lines to the rear of the control console. Before connecting these lines to the connectors on the trailer, bleed each fuel line separately into a container by briefly turning on each fuel pump to ensure that most of the air bubbles have been removed from the lines. Clean fuel may be returned to its respective reservoir.

20. Tighten all fuel line connectors to prevent leaks in the fuel delivery system.

### 4.4.1 Smoke Generator Electrical Console Operation

Verify that all electrical switches and fuel control valves are in the OFF position and then proceed with the following steps.

1. Turn main power switch to ON position.

2. Turn on stack transmissometer fans. Check fans visually to ensure that they are operating.

3. Turn the main blower on momentarily to ensure that it is operational. Then, turn off the main blower until you begin the actual smoke generation phase.

4. Activate the transmissometer and readout system (digital meter or strip chart recorder, or both) by turning the electrical point switch to ON position. Allow the electronic components to warm up for at least 30 minutes prior to attempting the calibration phase. Unless the drive mechanism of the strip chart recorder is driving the pen to its extreme positions do not adjust the controls during this warmup period. Proceed with calibration of the transmissometer system. See Section 4.3.1 for additional details.

*5. Establish 0 and 100 percent span adjustment of transmissometer. This procedure varies slightly depending on whether the readout system is a strip chart or digital recorder device. Refer to your generator's operating manual for detailed instructions on the specific readout system on your smoke generator.

### 4.4.2 Recorder Transmissometer Readout System

Although procedures will vary depending upon the manufacturer, the following steps can generally be followed.

1. Turn light source to OFF position.
2. Adjust transmissometer zero control to read 100 percent opacity on the chart scale.
3. Watch recorder for a few minutes to check for significant instrument drift.
4. Turn light source to ON position.
5. Adjust transmissometer span control on the recorder to read 0 percent opacity on the chart scale. Check for any significant drift or erratic changes in recorder setting. NOTE: The recorder readout may be in percent transmittance. This can be changed by reversing the recorder input leads.
6. Repeat steps 1 through 5 several times until the instrument stabilizes.

### 4.4.3 Digital Transmissometer Readout System

The following steps present a general procedure for span adjustment for digital transmissometer readout systems.

1. Turn light source to OFF position.
2. Adjust the control setting of the digital readout system to read 100 on the digital meter. This number actually represents 0 light transmission across the stack transmissometer, or 100 percent opacity.

3. Turn light source to ON position.
4. Adjust transmissometer zero control to read 0 on the digital panel meter.
5. Check for drift in both the 0 and 100 percent readout modes. Some drift is normal until the readout system has warmed up for about 30 minutes.
6. Repeat steps 1 through 5 several times to document instrument stability.

### *4.4.4 Response Time Test

Determine the response time by producing a series of five simulated 0 and 100 percent opacity values and observing the time required for stabilization. Opacity values of 0 and 100 percent may be simulated by alternately switching the light source power off and on while the smoke generator is not producing a plume. The actual time can be determined by use of a stopwatch. Optimum response time should be between 4 and 5 seconds, but no greater than 5 seconds. All response time checks should be recorded on a form similar to the one shown in Figure 8.

### *4.4.5 Transmissometer Calibration

Step-by-step procedures for the calibration of VE generators should be followed in detail as outlined in Section 4.3 of this report. The calibration procedures outlined in Method 9 are essential to the proper operation of a smoke generator and should be thoroughly understood by the generator operator.

### 4.4.6 Upper Stack Section Elevator

The following steps should be followed to properly elevate the generator's upper stack section.

1. Remove the stack cradle hold-down bracket.
2. Close hydraulic bleed valve at front of hydraulic pump reservoir.
3. Pump handle on hydraulic cylinder to raise stack.
4. Place a "C" clamp on flanges between stack sections for additional stability. NOTE: Do not pump handle after stack reaches the upright position. The stack can be damaged if additional force is applied by the hydraulic cylinder.

### 4.4.7 Procedures for Producing Black Smoke Plumes

Prior to beginning this subsection, complete the procedures outlined in Subsections 4.4.1 through 4.4.4. The following steps outline the procedure for producing black smoke plumes.

1. Be sure the stack transmissometer fans are operating properly.
2. Turn on the main blower fan.
3. Verify that the combustion chamber pilot light control valve and the white smoke generator gas control valve are turned off (clockwise).
4. Open the main control valve on the 20-lb propane bottle; this is the fuel for the white smoke generating unit.
5. Remove the heat register plate on the black smoke combustion chamber, move pilot control valve to the open position, and use a small propane torch to ignite the pilot flame inside the combustion chamber.
6. Replace the heat register cover plate. The adjustment arm for the register louvers should be located so that it cannot vibrate closed.
7. Adjust register louvers for proper air flow. This will require trial- and error-adjustments until the best settings are achieved.
8. Turn fuel pump electrical switch to toluene position as indicated on control panel.
9. Open toluene fuel control valve slightly to allow fuel lines to fill with toluene. This can be observed by watching the toluene flow in the input line connected at the rear of the generator trailer.
10. A small flame now should be evident inside the combustion chamber and the recorder should be indicating a low level smoke plume (less than 20 percent opacity).
11. Check to be sure that the pilot light is burning.
12. Check for possible fuel leaks at all connecting points in fuel lines and check for kinks or blockage in the fuel lines.
13. Turn off pilot light and determine whether fuel can flow into the fuel tray mounted inside the combustion chamber. Before attempting this, make sure pilot light is off. Do not attempt to light the unit if more than 0.25 oz toluene is in the fuel tray.

14. Allow sufficient time for removal of air from remote fuel lines.

15. Repeat the preceding steps if the system appears to be functional. If the unit fails to function, review all steps and details carefully until the problem is found and eliminated.

16. Allow the combustion chamber to warm up for a reasonable time before proceeding with 20 percent opacity. Allow a 10- to 20-minute warmup before starting the initial run.

17. The desired black smoke opacity readings now can be set by adjusting the toluene fuel control valve. Stable readings can be achieved after a few minutes practice. Best results are achieved with slow but firm changes in the control knob setting.

18. Readings of 80 percent opacity or higher should be held for only brief periods to protect the generator from excessive heat buildup.

19. The pilot light should be left on between black smoke runs and until the generator is shut down for the day.

20. Be sure that all toluene is burned out of the combustion chamber before proceeding to shut down the generator.

### 4.4.8 Black Smoke Assembly Shutdown Procedures

1. Turn fuel pump at control console to OFF position.

2. Turn toluene fuel control valve to OFF position.

3. Be sure all fuel is burned in the combustion chamber. This will be indicated by a few minutes of clear stack emissions.

4. Turn off main valve on propane bottle if no other runs will be conducted with either black or white smoke.

5. Cool the combustion chamber by running the main fan for at least 10 minutes after fuel shutdown.

### 4.4.9 Procedure for Producing White Smoke Plume

Prior to generating the white smoke, be sure that all the toluene is burned out of the black smoke combustion chamber before proceeding. The main blower should be turned on and running, and the front of the smoke generator trailer should be slightly elevated to prevent any fuel oil spillage from pooling in the vaporizer cabinet. The following steps outline the procedure for producing white smoke plumes.

1. Make sure the vaporizer burner valve is in the closed or OFF position (fully clockwise).

2. Open main valve on propane bottle.

3. Open lid on vaporizer assembly cabinet. Check for any fuel oil or liquid in the cabinet chamber.

4. Ignite the vaporizer burner flame with a small propane torch.

5. Adjust the vaporizer burner valve until there is a smooth blue flame at the input to the fuel vaporization burner chamber.

6. Allow the vaporization chamber to warm up for at least 5 minutes; a little longer time is needed in extremely cold weather. The intake throat of the vaporization chamber should appear slightly red before any No. 2 fuel oil is injected.

7. Slightly open No. 2 fuel oil valve on console fuel control panel. A low opacity white smoke plume now will be indicated on the console recorder and it will be visible from the stack.

8. If no white smoke is visible, shut off the fuel oil valve and check that the vaporizer burner is working.

9. Slowly open the fuel oil control valve one more time. White smoke should be indicated and visible.

10. If no smoke is produced, shut off the vaporizer burner and allow the unit to cool down.

11. Check for blockage or leaks in fuel oil lines.

12. Check to ensure that fuel oil will flow into vaporizing chamber.

13. If all checks are positive and no excess oil is in the vaporizer, repeat the startup steps. If the unit still does not generate, shut the unit down and repeat each step until the problem is found and corrected.

When the unit is ignited and operating, the white smoke vaporizer assembly should produce any desired opacity. Be sure to always guard against flooding of the fuel oil vaporization chamber. Do not open the fuel oil control valve beyond the initial point when 100 percent opacity is registered on the console opacity recorder.

### 4.4.10 White Smoke Assembly Shutdown Procedure

The following steps outline the proper shutdown procedure for the white smoke assembly.

1. Turn off the fuel pump at control console.
2. Turn off fuel oil control valve.
3. Allow all fuel to vaporize from the vaporization chamber. This will require only 2 or 3 minutes and will be indicated by a 0 percent opacity reading on the recorder.
4. Turn off vaporization chamber propane torch.
5. Turn off valve on propane bottle if no other runs are to be conducted with either white or black smoke or if the generator will be unattended over a lunch break, etc.
6. Run main blower for 10 minutes to cool vaporizer heat chamber.
7. At the completion of the certification runs, repeat the calibration procedures and record calibration data on the applicable forms.

### 4.4.11 Generator Shutdown

When the training session is over, the generator must be shutdown and secured for storage. The following steps outline the generator shutdown procedure.

1. Ensure that both fuel control valves are completely off (turned clockwise).
2. Be sure that all propane control valves are fully off (starting with the main bottle valve, the white smoke torch valve, and the toluene igniter valve).
3. Disconnect fuel lines at trailer and insert ends into their respective fuel storage tanks. If proper connect procedures were followed, the blue connector should go into the toluene tank and the green connector should go into the kerosene or fuel oil storage tank.
4. Disconnect fuel supply lines (the short set) from fuel storage tanks and elevate them to avoid unnecessary spilling of fuel. Turn on the fuel pumps to drain the lines of fuel.
5. Remove fuel lines from console disconnects. Elevate one end to fully ensure fuel drainage and cap the ends for storage.
6. Cap the male connectors on console.
7. Turn off the PA system. Disconnect the PA system components and store properly.

8. Turn off all electrical control switches, starting with the induced draft fan (when the generator has cooled sufficiently), then the recorder power control switches, and finally the main power switch.

9. Disconnect the generator from the AC power source.

10. Remove the electrical system interconnects from the trailer junction box and the rear of the console control panel. Coil and store the cables in a dry and secure facility.

### 4.4.12 Procedures for Lowering Upper Stack Section

The following procedure should be followed to properly lower the upper stack section.

1. Open cradle hold-down bracket.

2. Partially open hydraulic bleed valve.

3. Slowly tip the stack so it can work with the hydraulic system.

4. The stack can be lowered by inserting a large screwdriver between upper and lower stack flange sections and applying leverage.

5. Be careful not to let the stack get out of control and drop too suddenly. This can be controlled by careful adjustment of the bleeder valve.

6. Close stack cradle and secure in place for travel. Bleeder valve should be left open to prevent damage to stack caused by accidental activation of the pump.

### 4.4.13 Transporting Smoke Generator

The smoke generator is designed to be transported to various training sites to reduce student travel time and cost. The following items should be checked prior to transporting the generator.

1. Bolt down stack in the cradle support.

2. Protect fuel storage tanks by padding the inside portion of their storage compartments.

3. Check trailer tail lights and turn signals for proper operation.

4. Ensure that the tow vehicle is adequate and has the proper hitch assembly.

5. Check tires for proper inflation and be sure that the lug nuts are secure.

6. Be sure that the trailer and two vehicles have sufficient braking capabilities to ensure safe transport since the smoke generator is heavy.
7. Transport the control console inside the towing vehicle--not on the trailer.
8. Upon arrival at the designated training site, check the trailer and generator component system for possible damage, loose bolts, etc.

## 4.5 STORAGE AND MAINTENANCE OF THE SMOKE GENERATOR

Proper storage and maintenance procedures are essential for smoke generators since they not only increase the lifetime of the instrument but also provide better quality assurance.

### 4.5.1 Storage of Smoke Generator

The modern smoke generator is a complex and sensitive electronic instrument that requires care and protection in both handling and storage. The electronic console must be stored in either a heated facility or environment when not in actual operation, and must be covered with a plastic sheet when exposed to rainfall. The electrical interconnect cable can be stored in a generator storage compartment as long as it is reasonably dry. Although the basic smoke generator trailer unit can be stored outdoors, storing the unit in a warehouse or garage will increase its lifetime and result in lower maintenance requirements and operating costs. If the trailer is stored outdoors, the stack transmissometer section must be protected by a waterproof cover. A tarpaulin covering the entire generator may be used, but the covering must place no stress on the stack fans or the transmissometer electrical connection. Any unit stored in such a manner should be checked frequently to ensure the integrity of the protection.

### 4.5.2 Maintenance Procedures

Before and after each smoke school, the following routine maintenance procedures should be performed.

1. Check all electrical cables to verify that there are no frayed parts, that all contact points are clean, that the connectors are not bent, and that the cables have good integrity.

2. Check all fuel lines to ensure that they are unkinked; have no weathered or worn spots, splits, or leaks; and that the connectors are in good condition. Since ferrules can be easily lost inside the connectors, verify that these are present.
3. Use liquid soap or similar leak-check commercial products to check the integrity of the fittings to the propane tank for leaks.
4. Check the propane gas supply by weighing the cylinder.
5. Assemble and check the PA system to ensure proper operation. The PA system should be stored with the console unit.
6. Check that the small drain hole in the bottom of the stack is open so that water will not accumulate in the stack.
7. Check the transmissometer calibration to ensure that the system has not aged or deteriorated and that the calibration curve is still good.
8. Check the recorder pin assembly to ensure that it is operating correctly. This can be performed by turning on the transmissometer and turning the signal attenuator to the right and left to make sure that the recorder pin will travel up and down the scale. An alternate procedure is to turn the transmissometer on and off to ensure that the pin will drive back and forth smoothly from one side to the other.
9. Inspect the fire box after it has cooled by inserting a mirror in the side. Make sure that the torch and deflector plate are in good condition and that the fire box has not been damaged in transit.
10. Place a drop of oil on each of the bearing surfaces and in the oil drop slot on either side of the electric motor.
11. Verify that all storage compartments contain the appropriate items and that these compartments are locked.
12. Keep a bound logbook to record all events that bear on the performance of the smoke generator. Such events include records of all repair and maintenance work, spectral response checks, calibration checks, response time checks, dates of use, number of runs completed, best estimate of fuel consumption, and any other pertinent information. This book should be maintained by the generator operator and checked every six months by the training supervisor. Entries should be made whenever the generator is serviced, repaired, and/or operated.

## 4.6 COMMON PROBLEMS, HAZARDS, AND CORRECTIVE ACTIONS

The proper operation and maintenance of a smoke generator requires personnel with a high degree of skill and instrument knowledge. The training supervisor is responsible for ensuring that a qualified person is present and that proper calibrations, checks, and safety procedures are followed.

The generator should always be in top condition and ready to operate. To ensure optimum operation, the preliminary certification checks should be performed at least one day prior to the scheduled training and certification runs. For this preliminary run, the generator operator should review the applicable provisions of Method 9 and sections of this publication to ensure that all steps are performed.

A number of problems can develop that may interfere with the proper operation of the smoke generator. Some of the more common problems and solutions are discussed in this section.

### 4.6.1 Fuels

The use of improper fuels can cause several problems. The following fuel selection guidelines should be helpful in avoiding these problems.

#### 4.6.1.1 Black Smoke --

Originally, most smoke generators produced black smoke by the incomplete combustion of fuel oil. In the late 1960's, many operators found better results using benzene as the fuel. While benzene was fairly successful, it is a highly toxic substance and hazardous when improperly used. In June 1977, EPA issued a memorandum which stated that an adverse health problem may be associated with the use of benzene and strongly suggested that other fuels be used instead. Possible alternatives include toluene, xylene, kerosene, and No. 2 fuel oil. Table 2 lists the various properties of these fuels. Although all of these fuels are suitable, toluene appears to be the most suitable fuel for producing black smoke. Care must always be used when handling any fuel since they are flammable. Possible adverse health effects are also associated with prolonged and unnecessary exposure to benzene, toluene, and xylene.

TABLE 2. PROPERTIES OF CANDIDATE FUELS

| Fuel | Composition | Freezing point, °C | Boiling point, °C | Threshold limit value, ppm | Remarks |
|---|---|---|---|---|---|
| Benzene | $C_6H_6$ | 55 | 80 | 10 | Carcinogenic |
| Toluene | $C_7H_8$ | -95 | 111 | 100 | Requires increased accuracy in adjustment of fuel-to-air ratio compared with that required for benzene |
| Xylene | $C_8H_{10}$ | -25/+13 | 138-144 | 100 | Burns too hot |
| Kerosene | Higher paraffins and naphthenes | --- | 79-227 | a | Gives brown smoke |
| No. 2 oil | Paraffins, aromatics and napthenes | --- | 282 | a | Clogs valves |

[a] Threshold limit value will be greater than 100 ppm, although exact value depends on concentration of each specific compound.

### 4.6.1.2 White Smoke --

White smoke is made by vaporizing kerosene or No. 2 fuel oil. This usually is done by injecting the fuel oil either onto the hot exhaust from a self-contained gasoline engine or onto a heated surface, causing the liquid droplets to vaporize and then condense into a thick white cloud. Both fuels appear to perform equally well. The No. 2 fuel oil tends to clog the valves and produces slightly less smoke per gallon of fuel than does kerosene. Variations in the volatility of some kerosenes result in their tendency to ignite or flash when the vaporizer overheats. The operator should be aware of this and be prepared to react accordingly if kerosene is to be burned.

### 4.6.2 Overheating

Overheating either the combustion chamber or the vaporizer can permanently distort the unit, resulting in unstable smoke production or reduced opacity capability. Overheating is easily avoided by properly fueling the vaporizer and limiting the durations of high opacities. Once a vaporizer is severely damaged, it must be replaced in order to achieve satisfactory service.

### 4.6.3 Breakdowns

The new model generators are designed and fabricated for durable field use and portability. Like all electromechanical devices, however, the generator will occasionally break down or malfunction. The problem must be diagnosed and repairs made expeditiously to maintain the proper training and interest of the attendees. The inventory of spare parts should be based on the more common needs and malfunctions. Experience over the years shows most failures to be in the areas listed in Table 3.

### 4.6.4 Modifications to Improve Performance

In recent years, the operation of the smoke generator has been improved with a number of important modifications in:

- design of the black smoke combustion chamber
- switch from the exhaust manifold vaporizer to the hot plate vaporizer
- photopic transmissometer system

These improvements are adaptable to most basic generator units, if the frame and support assembly are sturdy and in good condition. Cost may be optimized by simply replacing the troublesome component. Outlined are some modifications that can be made, however, to improve the operation of some of the older model generators.

1. Place a baffle plate or refractory assembly in the air inlet opening of the combustion chamber to provide better air/fuel mixing conditions and to stabilize smoke production. Some experimentation may be needed to determine optimum location for the baffle.
2. Reduce fuel line plugging significantly by adding an inline fuel filter, which is standard equipment on the newer model generators.

TABLE 3. COMMON SMOKE GENERATOR MALFUNCTIONS

| Malfunction | Cause | Problem |
|---|---|---|
| Power failure | Overloading the circuit to blow a fuse or trip the circuit breaker; this should not occur because the generator should not overload the standard 110 VAC/15 A service | Locate service panel; check fuse or circuit breaker; replace or reset as necessary; if power fails again, the circuit is being overloaded; locate and use another electrical service |
| | Electrical connection has been broken or disconnected | Reconnect and secure |
| Loss of signal to the recorder | Light source burned out or broken | Replace bulb |
| | Loose wiring | Locate and repair loose connections; this condition is frequently intermittent and may require some movement of wiring and tracing and insulation with a test of a continuity meter |
| | 12 V power supply failure | Connect to a 12 V DC battery until power supply pack is replaced |
| Unstable smoke | Wind influences, e.g., > 15 mph | Check orientation of trailer in relation to wind direction; rotate trailer 30 to 60 degrees |
| Poor air/fuel mixture | Air flow into combustion chamber or deterioration of combustion chamber; wind direction may also be a problem | Determine most probable cause by inspection and experimentation; if combustion chamber is deteriorated or warped by heat, replacement may be required; attempt to install a baffle at air inlet by placing a brick or metal baffle in entrance |

(continued)

TABLE 3 (continued)

| Malfunction | Cause | Problem |
|---|---|---|
| Fuel flow problems or line blockage | Dirty fuel filters | Replace or install fuel line filters |
| | Fuel pump failure | Replace fuel pump; implement a temporary measure by switching the fuel lines to the operable pump; Note: Replacing fuel pump requires shutting off generator for 30 to 60 minutes if possible, replace at lunch break or end of day |
| | Fuel line kinks or plugging | Inspect fuel lines; if plugged, disconnect ends and blow out debris |
| | Carbonization of burner tips | Run a thin stiff wire through the orifice |

3. Minimize wind shear by increasing the main blower air flow since many of the older model generators have inadequate blower capacity. Wind shear is a common problem in areas that frequently experience wind speeds in excess of 12 mph. If the training session area has a prevailing wind direction, position the generator so that the wind does not blow directly into any openings in the smoke flow passages. If the wind shears off the plume at the top of the stack, a 90 degree elbow with laminar flow vanes may be used to allow the smoke to exit the stack parallel to the wind. This provides the trainees a better opportunity for certification by reducing the eddy effect. The elbow has been proven in field use, with some individuals reading successfully during winds exceeding 20 mph.

### 4.6.5 Safety Requirements

The normal safety requirements for trailer towing and handling apply to transporting the generator. Brakes, lights, etc. should be checked each time the trailer is moved. Wheel chocks must be used whenever the trailer is disconnected from a vehicle, and additional care must be exercised if the generator is located on an inclined surface.

Since smoke generation fuels are flammable, proper and sensible storage and handling precautions must be followed. Possible health hazards of handling the fuels should be recognized and the equipment should be operated only in open ventilated areas. Proper explosion-proof fuel should be used and any fuel transfer operations should be conducted with care. A fully charged and functional fire extinguisher must always be readily available whenever the generator is operating.

Because unit surfaces become hot while the generator is in operation, persons not involved and familiar with the equipment should remain at a safe distance. A pair of protective gloves should be available to handle any hot items, and operators should always wear safety glasses when working around the generator. Carelessness and shortcuts can result in serious injuries.

Some internal components of the console have a 110-V electrical charge that poses a potential hazard especially during damp field conditions. A voltmeter connected to a grounding rod can be used to monitor electrical shorting conditions.

## SECTION 5

## CERTIFICATION REQUIREMENTS

This section provides procedures for conducting the certification part of the training program. To ensure proper quality assurance, the certification must be attended by at least two people--one to operate the generator and the other to instruct the students, monitor student activity, ensure that the smoke is readable, answer student questions, grade records, etc. A third person is also recommended to assist with the above activities as well as to provide an additional element of quality assurance, especially for classes with 25 or more trainees.

Prior to firing up the generator, the instructor should identify the components, explain the operation of the generator to the trainees, and allow them to examine the equipment. Safety requirements should be discussed, and the trainees should be reminded to stay away from the generator during training and test runs. The instructor should also emphasize that the generator has hot surfaces that can cause serious burns and that there are numerous electrical cables and fuel lines which, if accidentally disconnected, could shut down the generator and delay the entire program.

The first part of the certification test will be a "test run." Both black and white smoke will be emitted, and the opacity announced in order to familiarize the trainees with the procedures and help "calibrate the eye" to the announced readings.

After the initial test run, certification runs will be made in blocks of 50 readings (25 black and 25 white). After the certification criteria have been achieved, the trainee must check that the form has been completed correctly and signed. It also is recommended that the trainee recheck the arithmetic on the form to avoid any errors in transcription or arithmetic that might preclude certification. Each form will then be checked by at least two other people to further assure that all criteria and requirements have been satisfied. Those trainees who successfully meet the criteria will receive a letter of certification and a copy of the qualification form.

The original qualification form is retained by the school for at least 3 years for possible presentation in any future legal proceedings or challenge of certification. Note: Certification is valid for a period of only 6 months according to Method 9.

Recertification procedures are identical to testing procedures, except that the lecture series is usually omitted. Though presently not required, it is recommended that the trainee repeat the entire lecture portion of the school every third year to reemphasize techniques and to familiarize the trainee with new material and procedures.

## 5.1 PRACTICE SESSIONS

Prior to the actual certification runs, the trainee should be exposed to a series of practice readings over the full range of opacity levels in order to allow an adjustment or "eye calibration" period. Calibration with the standards is an important element of the 6-month recertification requirement of Method 9. Trainee calibration can be achieved in several ways, although experience has shown that one of the most effective methods is to focus on the 25, 50, and 75 percent opacity levels.

The practice procedures consist of the following steps outlined in the flow chart diagrammed in Figure 18.

1. Set up the generator and perform the zero and span checks.
2. Set the chart speed to zero.
3. Distribute practice test forms (Figure 19) and explain their use. The first blank on the form is for the trainee's observed opacity estimate, the second for the announced transmissometer readings, and the third for the difference in the two values.
4. Generate a 25 percent opacity white smoke plume for about 3 minutes.
5. Encourage the observers to walk around and view this opacity level at different angles to the sun.
6. Repeat steps 4 and 5 for 50 and 75 percent opacity. Note: Standards of 20, 40, 60, and 80 percent opacity can also be used.
7. Begin the practice certification when the smoke becomes steady; indicate the beginning of the reading with the word "Ready."

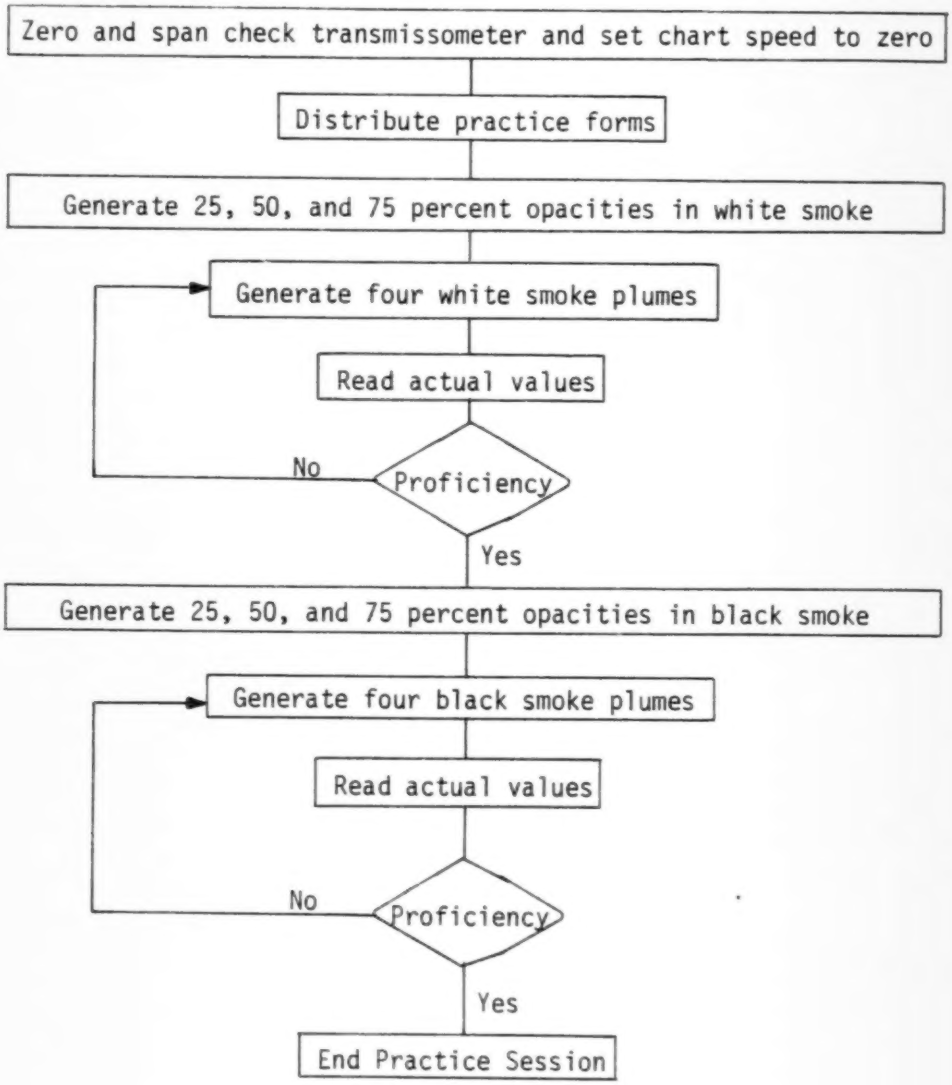

Zero and span check transmissometer and set chart speed to zero
Distribute practice forms
Generate 25, 50, and 75 percent opacities in white smoke
Generate four white smoke plumes
Read actual values
Proficiency
No
Yes
Generate 25, 50, and 75 percent opacities in black smoke
Generate four black smoke plumes
Read actual values
Proficiency
No
Yes
End Practice Session

Figure 18. Procedure for practice session.

|  | Plume No. | Run No. 1[1] |  |  | Run No. 2[1] |  |  | Run No. 3[1] |  |  | Run No. 4[1] |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Obs | SG | Dev | Obs | SG | Dev | Obs | SG | Dev | Obs | SG | Dev |
| Group Color:<br>W B | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |
| Group Color:<br>W B | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |
| Group Color:<br>W B | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |
| Group Color: | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  |  |  |  |  |  |

[1] Obs stands for the observer's opacity reading, SG, the opacity from the smoke generator, and Dev, the difference between the two.

Figure 19. Opacity reading training form.

8. Wait at least 1 second and say "Mark" to indicate that the observer should record his observation, which he estimates at the moment "Mark" is announced.

9. On a duplicate practice form, record the transmissometer value at the moment "Mark" is announced.

10. Repeat steps 7 through 9 four times for values around the standards, e.g., 25, 50, and 75 percent opacity.

11. After four different opacities are generated, read the actual values recorded for the transmissometer and have the trainees check their answers. Repeat steps 7 through 11 with smaller shifts in opacity until the trainees become proficient at judging opacity in increments of 5 percent.

12. Shutdown the white smoke generator.

13. Start up the black smoke generator.

14. Repeat steps 4 through 11 for black smoke plumes.

15. Shutdown the black smoke generator.

After the practice sessions, begin the actual certification testing.

## 5.2 CERTIFICATION TESTING

The trainees should now be prepared for the certification runs. They have been exposed to the theory and background on opacity, proper techniques of reading, parameters of variables that influence accuracy of readings, legalities of sound documentation, and plume opacities simulated by the smoke generator.

### 5.2.1 Preparing for Certification

The training supervisor and assistant must pay careful attention to the details of the certification operatives, and the staff must be able to state with certainty that all aspects of Method 9 have been fulfilled. This requires meticulous care of all records and information and stipulated QA checks of these procedures, thereby ensuring that any passing trainee is technically and legally certified.

An important element of the QA program is a checklist that itemizes the important steps in the certification of opacity readers. This checklist fulfills two important QA needs:

1. It assures that an orderly preparation and implementation procedure has been completed.
2. It provides documentation and evidence in support of quality certification.

Figure 20 presents an example format for the checklist, which should be marked off or initialed as appropriate after each item is completed. The training supervisor should check and sign the sheet at the end of the certification exercise. This form then becomes a part of the official file or record of the course.

### 5.2.2 Test Forms and Recording Procedures

Test forms vary greatly with the specific needs and experiences of each agency. A commonly used form that is both low in error and easy to grade is shown in Figure 21. The test form should be printed on two-copy paper so that the original can be turned in for the official file and the carbon copy can be graded by the trainee. Two test forms printed on regular bond paper with carbon paper between them is also satisfactory, although this arrangement is more cumbersome to use and subject to greater error and misunderstanding in reconciling the original with the carbon copy. In all cases, the agency should retain the original test page for the official file and certification record.

The trainee is to circle one answer per line that is judged to be the generator opacity at the indicated signal for reading and may change any answer by simply Xing out the wrong answer and circling the new choice as indicated in the following example:

20 25 ~~[✓ 30]~~ [✓ 35] 40 45 50

It should be noted that the most common error with this form is placing the answer on the wrong line. Again, the procedure is to X the incorrect answer and circle the correct one.

20 25 [✓ 30] 35 40 45 50
20 25 ~~[✓ 30]~~ [✓ 35] 40 45 50

Date: ______________________ Agency: ______________________

Operators: ______________________ Location: ______________________

______________________ ______________________

______________________ ______________________

Note: Initial each item as completed. Write NA (Not Applicable) where procedure does not apply.

Generator Preparation

Check for damage and vandalism ________

Verify that a complete inventory of parts and supplies (refer to inventory list) exists ________

Check inflation of tires ________

Check operation of brakes, hitch, safety chain, etc. ________

Lubricate fans and motors ________

Check that stack is secure for traveling ________

Perform preliminary check of console ________

Adequate Fuel Supply

Toluene ________

Diesel or kerosene oil ________

Propane ________

Other (specify kind and use) ______________________

Generator Setup

Check background, sky, and wind conditions for best generator orientation ________

Figure 20. Operator's smoke generator checklist.

(continued)

Figure 20 (continued)

Check electrical service and availability (110 VAC/20 A, 3 wire grounded connection) __________

Ensure that generator is leveled and wheels are chocked __________

Connect fuel and electrical lines __________

Check for fuel leaks (lines, connections, and tanks) __________

Check fans for smooth, normal noise level operation

- Main or induced draft fan __________
- Transmissometer fans __________

Be sure air volumes appear adequate __________

## Operation of Generator

Be sure generator logbook is available __________

Be sure that both fuel pumps are operable __________

Check chart recorder operation and paper supply __________

Check that all fuel valves are in full OFF position __________

Check both combustion systems for operating condition __________

Check operation of safety ignitors __________

Turn on console for 30-minute electrical warmup __________

Verify that all readout systems are working __________

## Transmissometer System Calibration

Zero and span check __________

Drift check __________

Response time __________

(continued)

Figure 20 (continued)

Light source voltage __________

Calibration error (use NBS filters) __________

Calibration record completed __________

### Generation of Smoke

Raise and secure stack __________

Run black smoke stability and range test __________

Run white smoke stability and range test __________

Check for excessive leaks and proper draft conditions __________

### Public Address System

Check that Total Smoke System is calibrated and operating properly for training and certification purposes __________

Comments -- please list any problems or conditions encountered in the setup or startup of the smoke generator.

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

______________________________________________________________

AFFILIATION____________________ NAME____________________ RUN #__________

Course Location____________________ Sunglasses____________________

Date____________________ Sky_______________ Wind_______________

Distance and Direction to Stack________________________________________

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 1 |
| 2 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 2 |
| 3 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 3 |
| 4 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 4 |
| 5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 5 |
| 6 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 6 |
| 7 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 7 |
| 8 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 8 |
| 9 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 9 |
| 10 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 10 |
| 11 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 11 |
| 12 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 12 |
| 13 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 13 |
| 14 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 14 |
| 15 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 15 |
| 16 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 16 |
| 17 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 17 |
| 18 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 18 |
| 19 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 19 |
| 20 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 20 |
| 21 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 21 |
| 22 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 22 |
| 23 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 23 |
| 24 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 24 |
| 25 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 25 |

DEVIATION_______________

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 26 |
| 27 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 27 |
| 28 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 28 |
| 29 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 29 |
| 30 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 30 |
| 31 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 31 |
| 32 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 32 |
| 33 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 33 |
| 34 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 34 |
| 35 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 35 |
| 36 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 36 |
| 37 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 37 |
| 38 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 38 |
| 39 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 39 |
| 40 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 40 |
| 41 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 41 |
| 42 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 42 |
| 43 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 43 |
| 44 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 44 |
| 45 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 45 |
| 46 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 46 |
| 47 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 47 |
| 48 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 48 |
| 49 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 49 |
| 50 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 50 |

DEVIATION_______________

Figure 21. Sample certification test form.

The form should be completed with one answer per line and all the pertinent information provided (see Figure 22). All entries must be made in ink. The observer's name, affiliation, run number, course location, and date should be recorded; if sunglasses are used, the type and lense color should be noted.

The windspeed should be estimated to within a 3 to 5 mph range. If an anemometer is not available, the Beaufort wind scale, Figure 23, may be used.

Smoke school certification should not be attempted in winds above 25 mph which interfere with high quality, stable smoke simulation. A personal discomfort factor under these conditions tends to introduce an additional unacceptable error.

The wind direction can be estimated to within eight points of the compass (N, NE, etc.) by observing which way a flag is blowing, or by observing the direction a few blades of grass are blown when thrown into the air. The north direction can be obtained by referring to a map.

The sky condition should be filled in as:

1. clear - less than 10 percent of the sky covered with clouds
2. scattered - 10 to 50 percent of the sky covered
3. broken - 50 to 90 percent of the sky covered
4. overcast - more than 90 percent of the sky covered

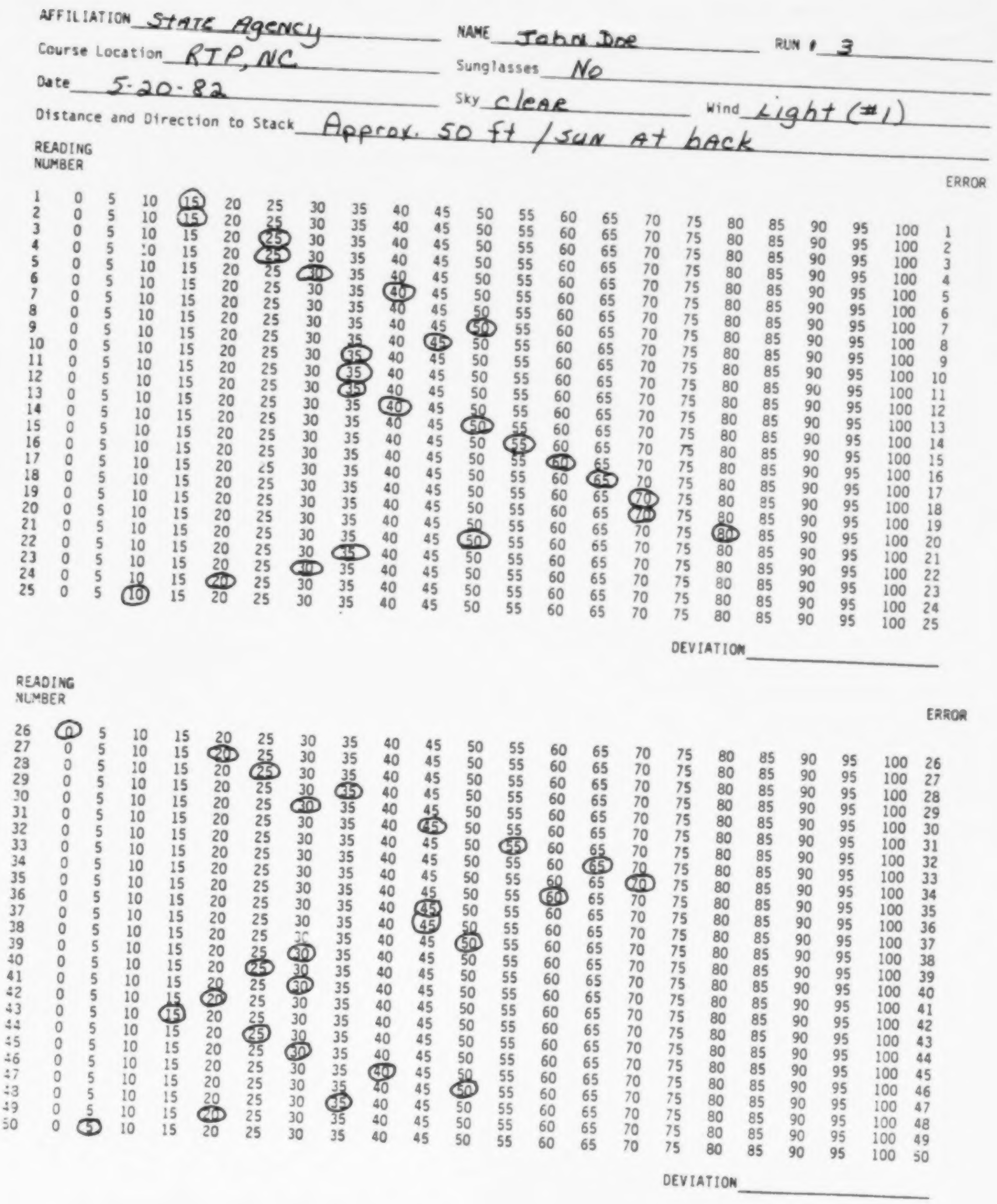
Certification can be achieved even under total overcast conditions provided the trainees have a contrasting background available. Readings should not be attempted during conditions of precipitation.

The observer's orientation with respect to both the plume and the sun should also be indicated on the test form.

### 5.2.3 The Test

The trainees should now be familiar with the testing procedures and ready to begin actual certification runs. The test forms should be distributed and the top portion filled in by the trainee for identification as described in Subsection 5.2.2.

Method 9 stipulates that a valid test must have 25 white and 25 black smoke plume readings. The candidate must demonstrate the ability to assign opacity readings in 5 percent increments, within the following criteria:



AFFILIATION State Agency NAME John Doe RUN # 3
Course Location RTP, NC Sunglasses No
Date 5-20-82 Sky clear Wind Light (#1)
Distance and Direction to Stack Approx. 50 ft / sun at back

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 5 | 10 | [✓ 15] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 1 |
| 2 | 0 | 5 | 10 | [✓ 15] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 2 |
| 3 | 0 | 5 | 10 | 15 | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 3 |
| 4 | 0 | 5 | 10 | 15 | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 4 |
| 5 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 5 |
| 6 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | [✓ 40] | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 6 |
| 7 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 7 |
| 8 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 8 |
| 9 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ 45] | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 9 |
| 10 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 10 |
| 11 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 11 |
| 12 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 12 |
| 13 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | [✓ 40] | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 13 |
| 14 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 14 |
| 15 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | [✓ 55] | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 15 |
| 16 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | [✓ 60] | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 16 |
| 17 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | [✓ 65] | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 17 |
| 18 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | [✓ 70] | 75 | 80 | 85 | 90 | 95 | 100 | 18 |
| 19 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | [✓ 70] | 75 | 80 | 85 | 90 | 95 | 100 | 19 |
| 20 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | [✓ 80] | 85 | 90 | 95 | 100 | 20 |
| 21 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 21 |
| 22 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 22 |
| 23 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 23 |
| 24 | 0 | 5 | 10 | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 24 |
| 25 | 0 | 5 | [✓ 10] | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 25 |

DEVIATION ______

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | [✓ 0] | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 26 |
| 27 | 0 | 5 | 10 | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 27 |
| 28 | 0 | 5 | 10 | 15 | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 28 |
| 29 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 29 |
| 30 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 30 |
| 31 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ 45] | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 31 |
| 32 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | [✓ 55] | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 32 |
| 33 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | [✓ 65] | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 33 |
| 34 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | [✓ 70] | 75 | 80 | 85 | 90 | 95 | 100 | 34 |
| 35 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | [✓ 60] | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 35 |
| 36 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ 45] | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 36 |
| 37 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ 45] | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 37 |
| 38 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 38 |
| 39 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 39 |
| 40 | 0 | 5 | 10 | 15 | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 40 |
| 41 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 41 |
| 42 | 0 | 5 | 10 | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 42 |
| 43 | 0 | 5 | 10 | [✓ 15] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 43 |
| 44 | 0 | 5 | 10 | 15 | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 44 |
| 45 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 45 |
| 46 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | [✓ 40] | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 46 |
| 47 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 47 |
| 48 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 48 |
| 49 | 0 | 5 | 10 | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 49 |
| 50 | 0 | [✓ 5] | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 50 |

DEVIATION ______

Figure 22. Example completed certification test form.

Beaufort Scale of Wind Force
(Compiled by U.S. Weather Bureau, 1955)

| Beaufort number | Miles per hour | Knots | Wind effects observed on land | Terms used in USWB forecasts |
|---|---|---|---|---|
| 0 | Less than 1 | Less than 1 | Calm; smoke rises vertically | |
| 1 | 1-3 | 1-3 | Direction of wind shown by smoke drift; but not by wind vanes | Light |
| 2 | 4-7 | 4-6 | Wind felt on face; leaves rustle; ordinary vane moved by wind | |
| 3 | 8-12 | 7-10 | Leaves and small twigs in constant motion; wind extends light flag | Gentle |
| 4 | 13-18 | 11-16 | Raises dust, loose paper; small branches are moved | Moderate |
| 5 | 19-24 | 17-21 | Small leaves in trees begin to sway; crested wavelets form on inland waters | Fresh |
| 6 | 25-31 | 22-27 | Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty | Strong |
| 7 | 32-38 | 28-33 | Whole trees in motion; inconvenience felt walking against wind | |
| 8 | 39-46 | 34-40 | Breaks twigs off trees; generally impedes progress | Gale |
| 9 | 47-54 | 41-47 | Slight structural damage occurs; (chimney pots, slates removed) | |
| 10 | 55-63 | 48-55 | Seldom experienced inland; trees uprooted; considerable structural damage occurs | Whole Gale |
| 11 | 64-72 | 56-63 | Very rarely experienced; accompanied by widespread damage | |
| 12 or more | 73 or more | 64 or more | Very rarely experienced; accompanied by widespread damage | Hurricane |

Figure 23. Beaufort Scale of Wind Force.

1. No reading may be in error by more than 15 percent opacity.
2. The average error must not exceed 7.5 percent for either set of 25 white or 25 black smoke readings.

Failure to meet either of these criteria is considered to be an unacceptable demonstration of reading accuracy, and the observer has failed that particular run of 50 readings.

The runs can be repeated as many times as needed to meet the criteria for certification. A minimum of 10 runs should be made available during a given certification session. Generally, students pass certification in three or less runs and more than 95 percent pass within the 10 runs. The steps below are to be followed in the testing session:

1. Set up the generator, allow warmup period, and perform the zero and span checks.
2. Distribute the certification forms, and have the trainees fill out the top (Figure 22).
3. Open the white smoke valve.
4. Generate the first standard opacity smoke plume.
5. Turn off all valves. Wait until emissions are not visible and the transmissometer trace is flat.
6. Repeat zero and span checks.
7. Announce the start of the test, give the run number and time.
8. Start the strip chart recorder.
9. Open the fuel valve and allow the smoke to stabilize within 1.5 percent opacity of a 5 percent scale line (Figure 13).
10. When the smoke has stabilized, say "Number one" and begin the trace on the strip chart.
11. After 1 to 2 seconds, say "Mark" if this reading stayed within the 1.5 percent opacity limits. Stop the recorder and number the reading. Restart the strip recorder. If unacceptable, say "Scratch" and repeat the recorder. Students do not mark their papers unless "Mark" is announced. Mark the unacceptable reading "Void" on the chart and initial.

12. Repeat steps 8 through 10 for the remaining 24 white smoke readings. The opacity of these readings must be selected in a random order.

13. Shut off the white smoke valve.

14. Check the zero and span transmissometer drift. If the values are within 1 percent of 0 and 100, go on to step 15. Otherwise, wait 15 seconds and repeat the check.

15. Open the black smoke valve and proceed with steps 4 through 11 for readings 26 to 50. The opacities must again be selected at random.

16. Collect the original or top sheet of the two-part form. After all trainee forms have been collected, give the correct readings. This allows the trainees to check their own reading so they can adjust and calibrate their readings as necessary.

In general, people frequently tend to read either slightly higher or slightly lower than the actual value. If that is happening, the observer can make the mental adjustment and at that point can proceed refining and reinforcing his skill. It is suggested that the trainees continue their readings for all runs even though they may have certified in the first few runs. This additional practice serves to refine the newly developed skills. This is not as important during recertification tests, however, especially if the person is routinely engaged in making official opacity readings.

### 5.2.4 Ensuring a Valid Certification Run

The instructor must make sure that the trainees read the plume opacity at the same time the transmissometer records the opacity. Many schools rely on audible signals for informing the trainees when to read the plume. A major problem with this is that some trainees tend not to read instantaneously, as suggested, but rather give the plume a lingering stare. This is a common reason for failure to certify, since the transmissometer reading may have already started moving to the next opacity reading. Readings must be made within a second of notification to mark.

This potential problem can be corrected easily by using a public address system to cue the readers and by modifying the chart recorder so that the pen gives an instantaneous rather than a continuous trace. A rubber band should be wrapped around the tracing bar and anchored to a heavy paper clamp on top of the console. When the generator has sufficiently stabilized for the first reading, the operator should place a finger on the trace bar. While pressing down on the trace bar to allow the pen to contact the paper, he should simultaneously announce "Number one." The pen should trace for 2 to 3 seconds. The operator should then release the bar simultaneously and announce "Mark." The trainees should be instructed to read between the two announcements of "Number one" and "Mark." This results in an exact trace of the transmissometer reading during the precise period the students are to read. Should the smoke destabilize and cause the opacity to jump greater than ±2 percent, the instructor should void that number by announcing "Scratch" and indicate it on the chart record.

The generator operator should circle and number each acceptable trace for full and accurate identification. He should indicate with an X any unacceptable trace, write VOID adjacent to it, and initial it to avoid any confusion on the validity of readings. The traces on the strip chart recorder discussed above are illustrated in Figure 13. The operator should clearly mark the strip chart at the beginning and end of each run and identify each run with the date, time, run number, and color of smoke. This is easily accomplished by use of a rubber stamp similar to the one illustrated in Figure 24. The operator should note and initial any event that could impact the validity of a run on the strip chart. In addition, any lengthy or detailed explanation should be noted in the bound logbook.

METHOD 9 CERTIFICATION RUN

DATE____________________

RUN #____________________

TYPE____________________

CHART SPEED_______________

+ STOP TIME_______________

OPERATOR_________________

Figure 24. Certification run identification stamp.

## 5.3 GRADING AND DOCUMENTATION PROCEDURES

If a test form similar to the one shown in Figure 24 has been used, accurate grading is relatively simple with the aid of a grading key. The moderator can produce this key by marking the correct value for each reading with a china marking pencil on an acetate copy of the form. The moderator should then place the acetate key over each form to be graded and identify the difference between the correct answers and the trainee's answers. With practice, an error exceeding 15 percent (three or more 5 percent increments) is quickly spotted.

The moderator should count the number of increments of 5 percent error for both sets of 25 readings and compare the average deviation ($\bar{D}$) for each run of 25 readings using the following equation:

$$\bar{D} = \frac{(\text{Sum of Positive Deviations}) - (\text{Sum of Negative Deviations})}{25}$$

An alternate system is to total the number of increments of 5 percent error (both positive and negative) and read the average deviation from the chart presented in Table 4. If a chart is unavailable, the total number of percent increments on 25 readings can be multiplied by 0.20 to get the average deviation. These two methods are illustrated in Figure 25.

Several different grading methods are used. Some training supervisors prefer that all grading be done by the course moderators without trainee participation. Involving the trainees, however, enhances learning. The moderator collects the original sheet of the test form at the end of each run. The trainee retains the second copy for initial grading. After all original copies for a run have been collected, the transmissometer opacity values are announced. The trainees grade their copy of the run. The generator operator can prepare a master copy of the opacity readings as the values are announced to be used as the acetate grading key for the official grading.

After the readings have been announced, the trainees are given a few minutes to check their paper and to recognize any needed adjustments in their reading skills. The training staff, however, must make the official determination of certification.

In sessions involving a large number of students, another run may be started while one staff member continues grading. The graded forms must be

TABLE 4. AVERAGE DEVIATION CHART

| Increment of error[a] | Average deviation, % | Increment of error | Average deviation, % |
|---|---|---|---|
| 1 | 0.20 | 26 | 5.20 |
| 2 | 0.40 | 27 | 5.40 |
| 3 | 0.60 | 28 | 5.60 |
| 4 | 0.80 | 29 | 5.80 |
| 5 | 1.00 | 30 | 6.00 |
| 6 | 1.20 | 31 | 6.20 |
| 7 | 1.40 | 32 | 6.40 |
| 8 | 1.60 | 33 | 6.60 |
| 9 | 1.80 | 34 | 6.80 |
| 10 | 2.00 | 35 | 7.00 |
| 11 | 2.20 | 36 | 7.20 |
| 12 | 2.40 | 37 | 7.40 |
| 13 | 2.60 | 38 | 7.60 |
| 14 | 2.80 | 39 | 7.80 |
| 15 | 3.00 | 40 | 8.00 |
| 16 | 3.20 | 41 | 8.20 |
| 17 | 3.40 | 42 | 8.40 |
| 18 | 3.60 | 43 | 8.60 |
| 19 | 3.80 | 44 | 8.80 |
| 20 | 4.00 | 45 | 9.00 |
| 21 | 4.20 | 46 | 9.20 |
| 22 | 4.40 | 47 | 9.40 |
| 23 | 4.60 | 48 | 9.60 |
| 24 | 4.80 | 49 | 9.80 |
| 25 | 5.00 | 50 | 10.00 |

[a] Each error of 5 percent opacity, either positive or negative, is counted as one increment.

| Reading | Deviation, % | Increment |
|---|---|---|
| 1 | + 5 | 1 |
| 2 | 0 | 0 |
| 3 | -10 | 2 |
| 4 | 0 | 0 |
| 5 | - 5 | 1 |
| 6 | -10 | 2 |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | -15 | 3 |
| 11 | 0 | 0 |
| 12 | + 5 | 1 |
| 13 | -10 | 2 |
| 14 | -10 | 2 |
| 15 | + 5 | 1 |
| 16 | 0 | 0 |
| 17 | 0 | 0 |
| 18 | 0 | 0 |
| 19 | + 5 | 1 |
| 20 | 0 | 0 |
| 21 | +10 | 2 |
| 22 | 0 | 0 |
| 23 | - 5 | 1 |
| 24 | - 5 | 1 |
| 25 | - 5 | 1 |
| TOTAL | 105 | 21 |

Method 1:

$$\bar{D} = \frac{(\Sigma \text{ pos read}) - (\Sigma \text{ neg read})}{25}$$

$$\bar{D} = \frac{30 + 75}{25} = 4.2\%$$

Method 2:

$\bar{D}$ = Number of 5% increments x 0.2

$\bar{D} = 21 \times 0.2 = 4.2\%$

Figure 25. Two methods for determining average deviation for 25 readings.

crosschecked for accuracy before a trainee is officially notified of certification. A copy is sent to the individual along with a letter of certification and preferably a wallet card stating the period of certification. Details of this technique are listed in the following step-by-step procedures.

1. Complete an official run of 25 white and 25 black readings.

2. Collect the original (top white) copy of each trainee's certification form (Figure 22). Place them in the field file and retain in the possession of a training staff member.

3. Take a blank certification form, remove the carbon copy, and place the test form on a clipboard.

4. Write "Master" in the space for the observer's name. Fill in the run number, date, location, and time of the test run.

5. Correctly record the values on the form as they are read from the strip chart. Be sure to ensure accuracy. Make five random rechecks with the chart record. Allow the trainees to grade their (carbon) copy as this is done.

6. Place a grading acetate over the master, watching alignment carefully.

7. Using a marking pencil make a diagonal slash from upper left to lower right (\) over each marked number on the grading master. File the acetate with the originals.

8. Turn the grading master over and record the names of the trainees who think they have qualified. Theirs are the first papers to be graded.

9. Remove those papers from the file. Select one and align the acetate over it.

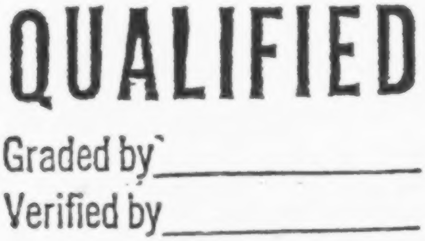
10. Count from the mark on the acetate to the mark on the trainee's paper. Each 5 percent is counted as one. For example:

| | | | | | |
|---|---|---|---|---|---|
| | (3) | (2) | (1) | | |
| 30 | 35 | 40 | 45 | 50 | Error = 3 |
| | Value | | | Correct value | |

11. Add all of the errors for the 25 white smoke readings and record the sum on the line marked "Deviation."

12. If no single error is more than 3 and the total number is 37 or less, repeat steps 9 and 10 for the 25 black smoke readings.

13. If no single error among the black smoke readings is more than 3 and if the total number is 37 or less, stamp the paper "Qualified" (Figure 26).
14. Sign the line labeled "Graded by," and have the supervisor verify the grade.
15. Enter the trainee's name, address, and qualifying run number in the VE program roster in a bound logbook (Figure 27).
16. Compute the average deviation for each color of smoke and record this value on the test form under "Deviation" in the roster.
17. Inform the trainees who have qualified.
18. Send a certification letter and wallet card to each trainee who qualified.



QUALIFIED

Graded by_____________

Verified by_____________

Figure 26. Certification stamp.

### 5.3.1 Maintenance of Records

The top sheet of the test form collected from each trainee at the end of each run is part of the documentation of an individual's certification as a qualified observer. A training staff member must collect these before announcing the correct values, and these forms must remain in staff custody thereafter. This control procedure prevents cheating or manipulation.

A bound logbook should be maintained for recording all events that might affect the performance of the smoke generator. This logbook should include records of repairs, maintenance work, spectral response checks, calibration checks, response time checks, etc. In another logbook, records should be kept of the number of attendees receiving training; the number of trainees certifying; and their name, address, scores and average deviation, dates of training, etc. The original of each individual's certifying run, the

Date: ______________________ Location: ______________________

Generator #: ______________________ Comments: ______________________

| Name and Address | Fee paid | Training | Recertifying | QR Number | Date | Dev. White | Dev. Black | Bias White | Bias Black | Certification |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
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Grader: Signature__________________ Initial___________ Date___________

Instructor: Signature______________ Date__________________________

Figure 27. Sample VE program roster.

checklist, the recorder strip charts, the VE program roster, and any other pertinent information should be maintained in the agency's official file.

This information may be needed for presentation at legal proceedings as evidence that the inspector or person in question has been certified as a qualified VE evaluator by a recognized smoke training and certification group.

These files should be arranged by training session and maintained for at least 5 years to be available for use in any future legal proceedings that may occur.

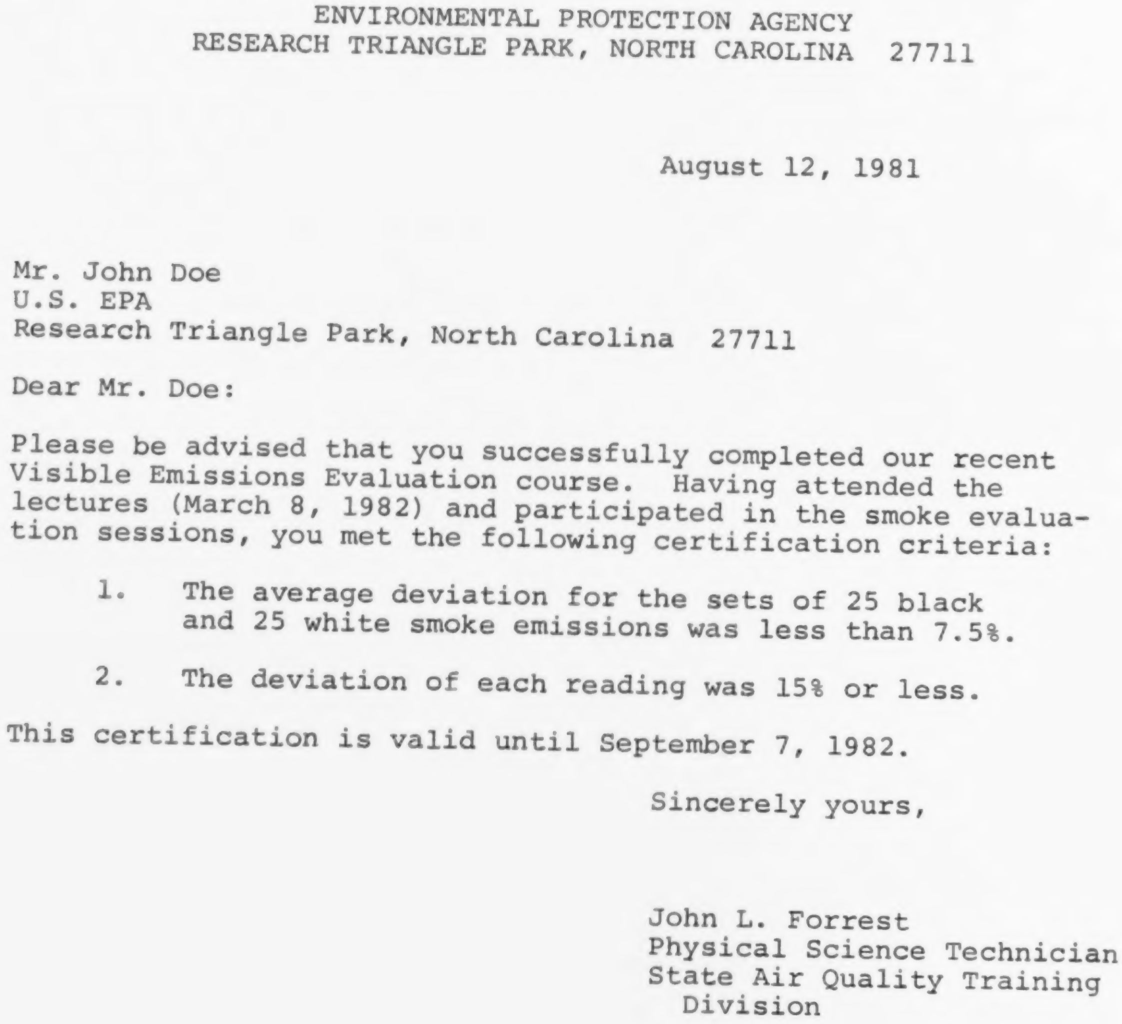
### 5.3.2 Certification Letters

Within 2 weeks of the training session, each trainee who successfully meets the Method 9 criteria should be mailed a letter of certification or verification and a copy of their qualification form. An example letter is shown in Figure 28.

Some agencies provide wall certificates and/or wallet cards to each successful participant. At least one of these should be provided and it should contain the following information:

1. Participant's name
2. State where accomplishment took place
3. Date of certification
4. Date of expiration or statement that certification expires 6 months from date of certification
5. Location of course
6. Signature of course moderator or other selected official

Certificates should be numbered in sequence and a record maintained in order to account for each certificate.



ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

August 12, 1981

Mr. John Doe
U.S. EPA
Research Triangle Park, North Carolina 27711

Dear Mr. Doe:

Please be advised that you successfully completed our recent Visible Emissions Evaluation course. Having attended the lectures (March 8, 1982) and participated in the smoke evaluation sessions, you met the following certification criteria:

1. The average deviation for the sets of 25 black and 25 white smoke emissions was less than 7.5%.
2. The deviation of each reading was 15% or less.

This certification is valid until September 7, 1982.

Sincerely yours,

John L. Forrest
Physical Science Technician
State Air Quality Training
Division

Figure 28. Certification letter.

# SECTION 6

# QUALITY ASSURANCE - TECHNIQUES AND PROCEDURES

Several recent court decisions have favored industrial efforts to resist, question, and discredit the application of opacity readings in enforcement/compliance documentation. Problems can be most readily avoided through a structured and consistently applied QA program that includes the elements stressed throughout the previous sections. Although this section will describe in concise detail a recommended program, it is not intended to represent the ultimate or ideal program. Each school should review its operations and needs, and then design an integrated QA program accordingly.

A QA program, in concept and implementation, is a management tool or operational mechanism for assuring credible training and certification. To ensure success, this program must receive the commitment, support, and follow-up of management. This additional effort will help to readily identify smoke school weaknesses and shortcomings that must be resolved. If properly implemented, this program will provide the extra element of documentation and credibility that will withstand the investigation and scrutiny of special interest challenges.

## 6.1 QUALITY ASSURANCE AUDITS

The QA program consists of two distinct program operations that are complementary and mutually supportive. One program is operated integrally with the presentation of the smoke school and focuses on the operation of the smoke generator. This program provides the extra effort needed to assure routinely accurate and reliable training and certification. Such an effort includes the planning of the program; preparation, calibration, and operation of the generator; recordkeeping and documentation; and trainee control. This program has been suggested and emphasized throughout the previous sections.

Another important element of QA is auditing. A VE program audit is an external review of the program by use of structured evaluation forms. The audit is usually conducted by supervisory personnel to assure objectivity. Audits are designed to identify program weaknesses and deficiencies that must be addressed and corrected in order to maintain an effective and high-quality opacity training and certification program.

A performance audit is a structured and routine review of the various steps in the training and certification process. It generally consists of a number of specified checks to ensure that proper and accurate procedural activities have been completed. The performance audit is conducted by the training supervisor and/or designated staff, and is most applicable to fairly specific and routine procedures. Appendix B includes example formats for inspection and operation of the smoke generator/transmissometer unit and the handling of certification test records. Although not addressed in this manual, additional performance audit formats could be developed for other specific procedures important to overall program quality assurance. In this process, the staff would systematically review the content and operation of the program as outlined in this manual. In any audit situation, checklists should be devised for each specific activity.

Records pertinent to the audit must be completed and maintained as part of the agency's official documentation file. The generator operating log, smoke school file, and other records are also components of the documentation and recordkeeping process. The importance of the performance audit as an integral part of the training activity cannot be overemphasized because it is vital to training and certification efforts. This audit provides assurance that the requirements of Method 9 have been fulfilled and that a sound and high-quality program has been provided.

Complementary to the performance audit is the system audit. The system audit is conducted periodically, perhaps on an annual basis, through an on-site comprehensive review of the total smoke school program. This audit should be conducted to assess all aspects of the training activity and should readily identify problems and weaknesses that should and can be corrected. The system audit preferably should be conducted by upper management such as the enforcement program manager and/or EPA Regional Office personnel. Participation by the enforcement program manager is preferable because opacity certification directly impacts and supports the day-to-day enforcement/compliance operation. This is particularly important since more than 90 percent of particulate emissions compliance is determined and documented by opacity readings. Participation by enforcement management also provides a needed element of management involvement and concern. The smoke school is typically a service provided by the Technical Support Division. It also demonstrates interest by the Enforcement Division in requiring the most credible operation possible.

A system audit should have a positive impact. Management attention, concern, and opacity training and certification should increase with increased court challenges and litigation. The system audit provides a mechanism for management to gain needed program familiarization. It can also be used as a planning document to assist agencies in obtaining the support to update training materials and equipment.

The system audit is a review of the entire training program and can be used to assist in a systematic check. An itemized audit form similar to the one included in Appendix B should be followed. The checklist approach assures that all aspects of the program are evaluated. It also lends itself to the expedient preparation of an audit report. The form can be attached to a brief narrative that summarizes the findings, conclusions, and recommendations. It also provides the mechanism for followup on the important recommendations to assure that proper corrective measures have been taken.

## 6.2 QUALITY ASSURANCE FOR CLASSROOM TRAINING

Quality assurance activities for the classroom portion of a training and certification program ensure that adequate facilities are available and that the lectures adequately cover important subject matter. A portion of the example system audit checklist included in Appendix B addresses basic requirements of classroom training. In addition to the system audit, the classroom examination can be used to evaluate lecture content and delivery. Evaluation questions can also be used to assess the adequacy of the classroom facilities (see example quiz in Appendix A).

## 6.3 QUALITY ASSURANCE FOR CERTIFICATION PROCEDURES

Because field certification activities are time consuming and expensive, this part of the training process must be completed accurately and expeditiously. Field activities must also be well documented. Recordkeeping functions for certification are amenable to a performance audit and are addressed in Appendix B, whereas the general QA review of the field certification program can be effected through a system audit.

Other factors that are important to the field certification program can be addressed as part of this system audit. These include the selection of an appropriate site, instructions to participants, operation of the generator, certification of generator outputs, and grading and documentation of reader results. Each of these components is addressed in the system audit checklist included in Appendix B.

The system audit checklist also presents additional factors to be considered in planning and performing the overall certification testing. Overemphasis of one area of certification, such as the field test, may result in understaffing of classroom or QA efforts. In addressing the criteria necessary to produce certified readers, the system audit checklist provides a method of assuring that all components are adequately evaluated.

## 6.4 TRACKING PROGRAM QUALITY

A principal objective of a QA program for VE training is to ensure that observers meet established performance standards. In addition, Reference Method 9 or other more stringent standards prescribe certain minimum levels of equipment quality and performance; therefore it is imperative that a mechanism exist to ensure compliance with these standards. Thus, a QA program must be able to track both qualitatively and quantitatively the overall program performance as well as the performance of individual program elements.

### 6.4.1 Analysis of Opacity Error

Some factors related to program performance are easily quantified because they can be directly measured, e.g., transmissometer accuracy and an observer's mean deviation. Other factors rely upon somewhat more subjective means for quantification, such as the use of examinations to determine the effectiveness of classroom training. In either case, the techniques used to make such quantification must maintain consistency since the performance tracking provided by a QA program relies upon comparable standards.

To a great extent, overall program performance can be judged by the opacity reading abilities of the trainees. Since the reading ability is really the combined result of the observer's ability, his classroom training, and the accuracy of the smoke generation equipment, however, potential and measured errors associated with each factor must be estimated. Appendix C details the procedure for calculating the overall bias and variability due to equipment and operational procedures. The general procedure requires the summation of variances or errors associated with each step in determining an opacity value and comparing that value and its associated error with the value observed by the attendees. Accordingly, error values must be determined for:

1. Standard opacity (calibration) filters
2. Transmissometer calibration
3. Reporting of opacity value (rounding-off)

The reported opacity value, which incorporates these errors, is then compared with the opacity values reported by the attendees. The bias and variance associated with differences in these two values describe the combined error of the attendee.

The error analysis outlined in Appendix C establishes the basis for determining the adequacy of an important element in a VE training school, i.e., to what accuracy can certified trainees read opacity. Secondarily, but of equal importance, the analysis provides a method for evaluating equipment status and the effectiveness of other elements of the overall program.

### 6.4.2 Evaluating Quality-Related Data

Accurate recording and analysis of program information are fundamental to a good QA program. In particular, the ability to compare current data with data from historical or contemporary programs is useful in assessing the achievement and maintenance of program quality. Close tracking of quality-related statistics can identify problems in classroom training and field certification and possibly prevent the unnecessary failure of smoke school participants.

Several statistics important to evaluating the training program's performance have already been discussed. These include assessment of operational error, which is an accumulation of several errors caused by calibration filters, transmissometer calibration, and opacity value reporting. The error of the individual reader is the main criterion for certification. For an overall training program, however, statistics representing group performance are of greater value. In particular, average observer bias and variance provide insight into overall participant performance and can identify training and equipment biases. Although the percentage of trainees certified is indicative of opacity reading ability, it is also a reflection of the effectiveness of classroom training. Figure 29 lists key statistics that can be useful in evaluating training school performances.

These statistics are of particular use for making comparisons with previous data or similar data from other VE training facilities. In this way, trends and significant deviations from a trend can be quickly observed. A useful tool for displaying quality control trends is the control chart. Values of significant parameters are plotted for succeeding periods of time or events, thus developing a trend line. Typically, lines indicating upper and lower acceptable values are also charted to clearly identify adverse trends. The major advantage of the control chart, or similar tracking systems, is that it clearly illustrates changes in factors indicative of program quality. It can therefore serve as a warning to supervisors that procedures and equipment may need review or may signify to management that a system audit is needed. A typical control chart is shown in Figure 30. A basic QA program would include the tracking of the statistics calculated in Appendix C and those of Figure 29.

Figure 31 lists some of these statistics in a checklist form suitable for auditing purposes. As may be noted, quality control criteria specified by Method 9 are included in the figures for ease of reference. Other criteria values in the figure represent those levels that reflect the experience of VE training schools with good QA programs.

Date: ______________________________ Location: __________________________

Instructors: ______________________________________________________________

Number of participants ______________________

Average of participants' mean deviations ______________________

Variance of participants' deviations ______________________

Average of participants' variance or standard deviation ______________________

Average of maximum positive and negative biases ______________________

Percentage of participants that certified ______________________

Percentage of participants that recertified ______________________

Percentage of participants failing due to mean deviation >7.5%, due to single deviation >15% ______________________
______________________

both ______________________

Percentage of participants that passed the classroom examination ______________________

Average examination score ______________________

Average years experience of participants ______________________

Percentage of participants within a given employment group (government, business, consultants, others) ______________________
______________________
______________________
______________________
______________________

Smoke generator calibration error ______________________

Opacity reporting error ______________________

Figure 29. List of statistics useful in evaluating VE training schools.

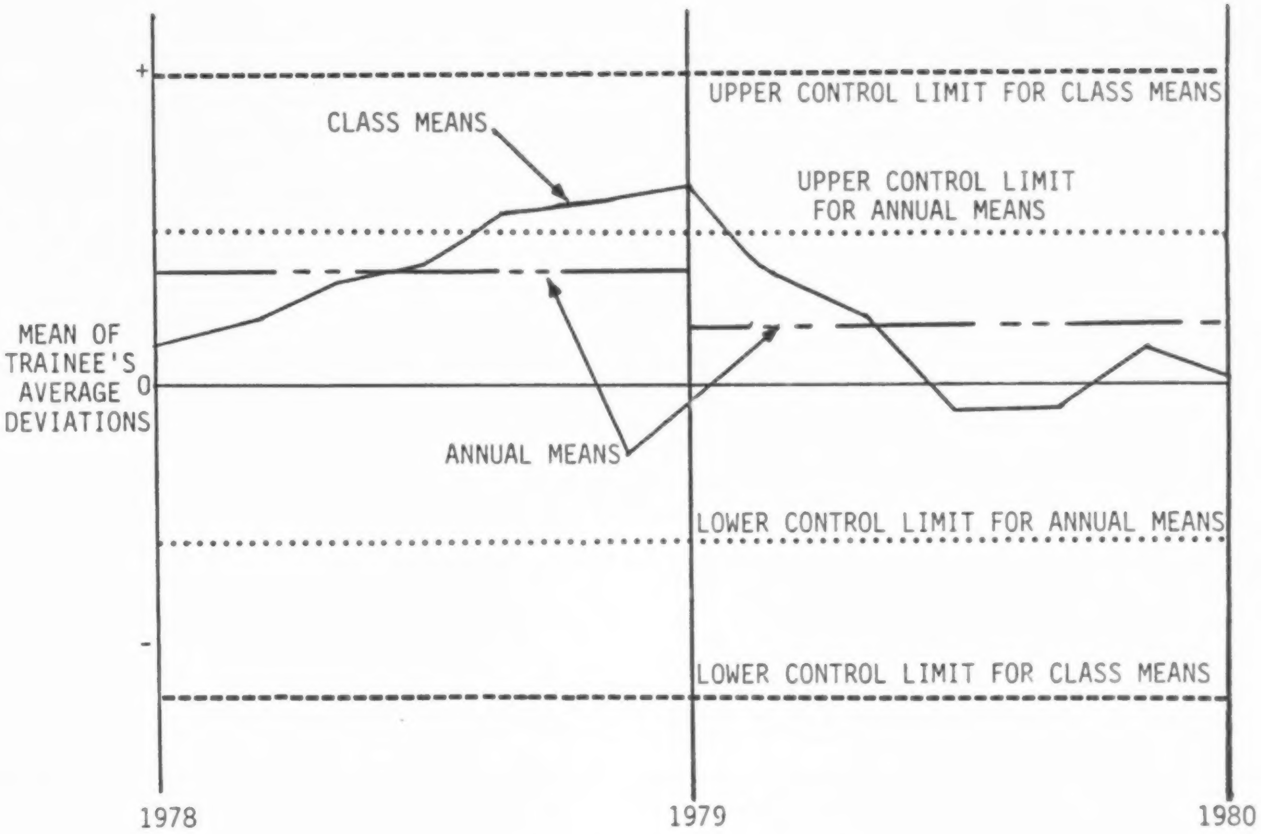


Figure 30. Example control chart for tracking training school performance.

| Statistics | Calculated value | Criteria value | Acceptable |  | Comments |
|---|---|---|---|---|---|
|  |  |  | yes | no |  |
| Calibration filter error |  |  |  |  |  |
| Bias[a] $\bar{X}_2$<br>$SD_1$ |  |  |  |  |  |
| Total error<br>($\bar{X}_1 \pm 2SD_1$) |  | 2%[b] |  |  |  |
| Transmissometer calibration error |  |  |  |  |  |
| Bias[a] $\bar{X}_2$<br>$SD_2$ |  |  |  |  |  |
| Total error<br>($\bar{X}_2 \pm 2SD_2$) |  | 1%[b] |  |  |  |
| Opacity reporting error |  |  |  |  |  |
| Bias[a] $\bar{X}_3$<br>$SD_3$ |  |  |  |  |  |
| Total error<br>($\bar{X}_3 \pm 2SD_3$) |  | 1.5% |  |  |  |
| Overall SG/T[c] error |  |  |  |  |  |
| Bias $\bar{X}_{ov}$<br>$SD_{ov}$ |  |  |  |  |  |
| Overall error<br>($\bar{X}_{ov} \pm 2SD_{ov}$) |  | 2.5% |  |  |  |
| Student certification[a] |  |  |  |  |  |
| Percentage of students that certify |  | 90% |  |  |  |
| Percentage of students that recertify |  | 95% |  |  |  |

Figure 31. Statistics checklist form.

(continued)

Figure 31 (continued)

| Statistics | Calculated value | Criteria value | Acceptable | | Comments |
|---|---|---|---|---|---|
| | | | yes | no | |
| Percentage of students that fail due to: | | | | | |
| mean deviation >7.5% | | 2% | | | |
| single deviation >15% | | 8% | | | |
| Either mean deviation >7.5% or single deviation >15% | | 10% | | | |

[a] Specified in Reference Method 9.

[b] Calculated pursuant to Reference Method 9, i.e., the absolute value of actual deviations is used to determine mean deviations.

[c] Smoke generator/trainer.

## SECTION 7

## VISIBLE EMISSIONS TRAINING LITERATURE

The following is a list of selected references pertaining to visible emissions determinations and training programs.

Conner, W. D. Measurement of Opacity by Transmissometer and Smoke Readers, EPA Memorandum Report, 1974.

Conner, W. D., and J. R. Hodkinson. Optical Properties and Visual Effects of Smoke Plumes. Environmental Protection Agency. Office of Air Programs, Edison Electric Institute and Public Health Service, 1967.

Coons, J. D., et al. Development, Calibration, and Use of a Plume Evaluation Training Unit. JAPCA 15:199-203, May 1965.

Crider, W. L., and J. A. Tash. Status Report: Study of Vision Obscuration by Nonblack Plumes. JAPCA 14:161-165, May 1964.

Hamil, H. F., R. E. Thomas, and N. F. Swynnerton. Evaluation and Collaborative Study of Method for Visual Determination of Opacity of Emissions from Stationary Sources. EPA Contract 68-02-0626, U.S. Environmental Protection Agency, Research Triangle Park, N.C., January 1975.

Malmberg, K. B. EPA Visible Emission Inspection Procedures. U.S. Environmental Protection Agency, Washington, D.C., August 1975.

Osborne, M. C., and M. R. Midgett. Survey of Transmissometers Used in Conducting Visible Emissions Training Courses. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, March 1978.

Ringelmann, M. Method of Estimating Smoke Produced by Undustrial Installations. Rev. Technique, 268, June 1898.

U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards, Emission Standards and Engineering Division, Evaluation of EPA Smoke School Results. October 9, 1974.

Weir, A., Jr., D. G. Jones, and L. T. Paypay. Measurement of Particle Size and Other Factors Influencing Plume Opacity. Paper presented at the International Conference on Environmental Sensing and Assessment, Los Vegas, Nev., September 14-19, 1975.

Wohlschlegel, P., and D. E. Wagoner. Visual Determination of Opacity Emissions from Stationary Sources. Guidelines for development of a quality assurance program, Vol. 9. EPA-650/4-74-005-i, U.S. Environmental Protection Agency, Washington, D.C., November 1975.

Yocom, J. E. Problems in Judging Plume Opacity: A Simple Device for Measuring Opacity of Wet Plumes. JAPCA 13:36, January 1963.

# APPENDIX A

# SAMPLE LECTURES FOR VE TRAINING PROGRAM

## LECTURE 1: HISTORY, THEORY, AND METHODS FOR EVALUATING VISIBLE EMISSIONS

This first lecture is designed to introduce the student to the history, principles, and theory of opacity. The instructor should reemphasize the purpose of the course and expand upon and clarify the introductory remarks during the orientation. He should explain that certification is necessary to assure VE evaluations and that it will be discussed in more detail later in the day. The lecture should cover each of the following points.

### History of the Method

The entire VE evaluation system is derived from a technical concept developed by Maximilian Ringelmann in the late 1800's to measure black smoke emissions from coal-fired boilers. The Ringelmann Chart, which was adopted by the U.S. Bureau of Mines in the early 1900's, has found extensive use in efforts to assess and control smoke emissions in this country. Since the early 1950's when the Ringelmann concept was expanded by the introduction of the term "equivalent opacity," the chart has become a very reliable and useful VE compliance/enforcement tool.

The Federal Government has discontinued the use of Ringelmann numbers in Method 9 procedures for Standards of Performance for New Sources (NSPS). The procedures are now based solely on opacity. Many states, however, still refer to the Ringelmann Chart to evaluate black and gray plumes in their regulations. The general trend, however, is to read all smoke as percent opacity. Certified evaluators must therefore be familiar with both systems.

### Opacity Theory

As the use of the Ringelmann Chart for assessing smoke emissions increased, considerable curiosity developed as to the theory and scientific foundation for this effective tool. This curiosity grew with the transition to use of opacity readings as the basis for evaluating visible particulate emissions of both white and black smoke. In practice, the evaluation of opacity by the human eye is a very complex phenomenon, and for the most part the theory behind it is not completely understood. It is well documented, however, that visible particulate emissions can be measured with good accuracy and reproducibility by properly trained/certified observers.

Previous study results indicate that plume opacity readings are influenced by many factors such as: particle density and particle refractive index, particle size distribution, plume background, pathlength, distance and relative elevation to stack exit, time of day, and lighting conditions. Of particular significance is particle size. Particles decrease light transmission by both scattering and direct obscurations. Particles in the diameter size range of visible light, 0.4 to 0.7 µm, have the greatest light-scattering effect.

By literal definition, opacity is the reduction in visibility of an object or background as viewed through the diameter of a plume; in terms of physical optics, opacity is dependent upon transmittance ($I/_{I_o}$) where $I_o$ is incident light flux and I, the light flux leaving the plume. Percent opacity is therefore defined as:

$$\text{Opacity} = (1 - I/_{I_o}) \times 100$$

The relationships between light transmittance, plume opacity, and Ringelmann number are presented in Table A-1.

TABLE A-1. COMPARISON OF LIGHT EXTINCTION TERMS

| Light transmission, % | Plume opacity, % | Ringelmann number |
|---|---|---|
| 0 | 100 | 5 |
| 20 | 80 | 4 |
| 40 | 60 | 3 |
| 60 | 40 | 2 |
| 80 | 20 | 1 |
| 100 | 0 | 0 |

## Opacity Reading Methods

Over the years, the procedures and guidelines for reading opacity have been refined and more rigidly defined. The three basic techniques currently used in reading visible emissions are:

1) Time exemption (frequency distribution)
2) Time averaging (Method 9)
3) Stopwatch (time accumulation)

Many states are using a combination of these procedures in opacity readings depending on the exact wording of the applicable emission regulation. The different techniques and provisions must be thoroughly understood, since legally sound opacity documentation must be consistent and in accordance with the applicable regulation. The three procedures are summarized below.

### Time Exemption --

Nearly all State Implementation Plan control strategies contain opacity regulations that are based on the time exemption procedure. This procedure, which historically was devised to control coal combustion sources, allows the source a stipulated number of minutes per hour to be in violation of the allowable emission level. The observer typically makes readings on 15-second intervals and reads for several minutes longer than the stipulated exemption period. The individual readings in excess of the allowable standard are then counted to determine the status of source compliance.

### Time Averaging --

Commonly referred to as EPA Method 9, this procedure was developed by EPA in support of NSPS and has been adopted widely by State and local air control agencies. This procedure also requires reading on 15-second intervals over a period of 6 minutes (24 consecutive readings). The sum of the readings is then mathematically averaged, and that value determines source compliance status.

### Stopwatch Procedure --

This procedure has recently been used by several air control agencies to more effectively address intermittent or highly variable emission levels, e.g., coke oven emissions. The observer uses two stopwatches. One watch is activated at the start of the observation period and stopped at the end. The second watch is activated in an accumulating time mode each time the emissions exceed the stipulated emission level and stopped each time the emissions fall below that level. The total accumulated time is then read and recorded from the second stopwatch over the total observation time of the first watch.

## Variables that Influence the Accuracy of Opacity Measurements

The human eye is a unique instrument for making opacity readings due to its capability to discern very narrow color bands of the electromagnetic spectrum and thus identify light wave frequency. The purpose of the VE training and certification program is to refine or calibrate the human eye to a scale that distinguishes opacity in 5 percent increments.

As previously mentioned, several factors influence the accuracy of opacity reading. The reader should understand these factors and take the necessary precautions to minimize errors. The standard observer form requires the observer to note and describe the conditions of reading that are needed to substantiate the validity of observations. This QA measure in the field reading and in the review of field reading by supervising personnel better assures sound documentation for enforcement purposes.

### Sun Angle --

Small particles in the plume tend to scatter light in the forward direction at small angles with reference to the direction of the sun's rays. Thus, a plume would appear to be much more opaque if it is not viewed with the sun behind the observer. The most accurate readings are taken when the sun is within a 140 degree sector behind the observer.

### Wind Direction --

It is important that the plume be read through a plume diameter approximately the size of the stack exit. If the plume is blown toward or away from the observer, it is likely to be read through a longer pathlength than if readings are taken with the wind blowing perpendicular to the line of sight. The longer the pathlength through the plume, the greater the plume opacity with diameters of constant loading and particle size distribution.

The error involved in observations made nonperpendicular to the plume is illustrated in the following example. Assume a plume rising from a rectangular stack with a width of approximately 2 ft has an opacity of 20 percent. Based on Beer's Law, the relationship between transmittance and pathlength is as follows:

$$I/_{I_o} = e^{-bL}$$

where b = the extinction coefficient of the plume; an intrinsic property of the plume due to particle characteristics

L = pathlength

For our example:

$$\text{opacity} = (I - I/_{I_o}) \times 100 = 20 \text{ percent}$$

$$I/_{I_o} = 0.80$$

$$L = 2 \text{ ft}$$

Solving for b:

$$\text{Ln } (0.8) = -b(2)$$

$$-0.223 = -2b$$

$$0.112 = b$$

On a 45 degree angle the actual pathlength (L'), as presented in Figure A-1, would be as follows:

$$L' = \frac{L}{\cos}(45^o) = \frac{2.0}{0.707} = 2.84 \text{ ft}$$

The apparent opacity is obtained by use of the extinction coefficient previously calculated (0.112) and substituting b and L' into Beer's law.

$$^I/_{I_o} = e^{-0.112\ (2.84)}$$

$$^I/_{I_o} = e^{-0.318}$$

$$^I/_{I_o} = 0.73$$

Thus, $$\text{opacity} = 1 - \frac{I}{I_o} = 0.27 \text{ or } 27\%$$

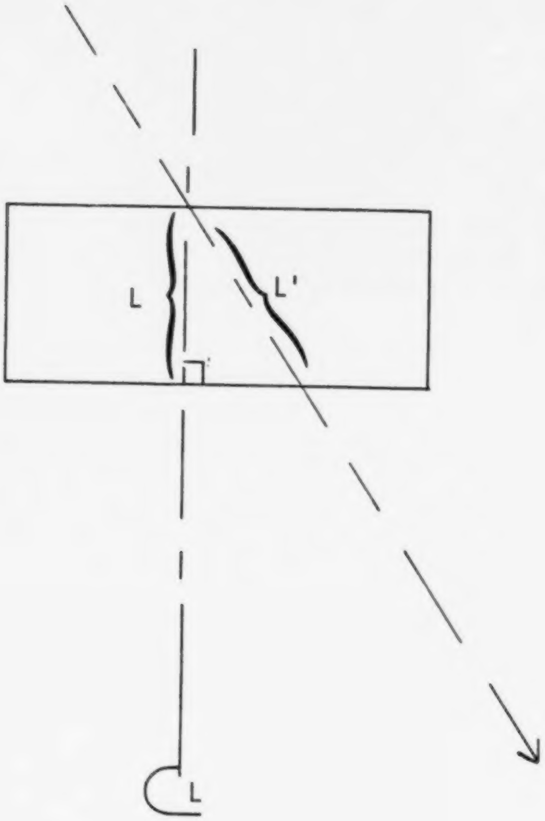


Figure A-1. Top view of discharge.

In this case, there was a 35 percent error between the two measurements. Proper positioning for plume observations is therefore influential to the accuracy of opacity measurements.

Variable wind conditions can cause the plume to shift, putting the observer in a poor viewing location. The observer should change positions if possible, maintain the proper sun angle, and remain perpendicular to the plume travel. Such changes must be noted on the recording form. If a suitable position cannot be found, the observer should note the conditions and discontinue reading until viewing conditions improve.

Effect of Observer Elevation Angle on Observed Opacity --

As the observer moves closer to the base of the stack, the angle of sight and the pathlength through the plume both increase, causing the observed opacity to increase even though the cross-plume opacity remains constant. Table A-2 illustrates how observed opacity decreases with distance from the base of a stack emitting a plume of 20 percent opacity. Figure A-2 presents the variation of observed opacity with distance from any elevated source. The observed opacity is 27 percent, as evaluated from a distance of one stack height (H), drops to 22 percent from a distance of 2H, and to 21 percent from a distance of 3H.

TABLE A-2. EFFECT OF ELEVATION ANGLE

| Observer distance (Y) | Observed elevation angle,° ($\theta$) | Observed pathlength ($P_o$) | Actual opacity, % ($O_a$) | Observed opacity, % ($O_o$) | Deviation, % |
|---|---|---|---|---|---|
| H | $45^o$ | 1.41 D | 20 | 27.2 | +7.2 |
| 2H | $27^o$ | 1.21 D | 20 | 22.2 | +2.2 |
| 3H | $18^o$ | 1.05 D | 20 | 21.0 | +1.0 |

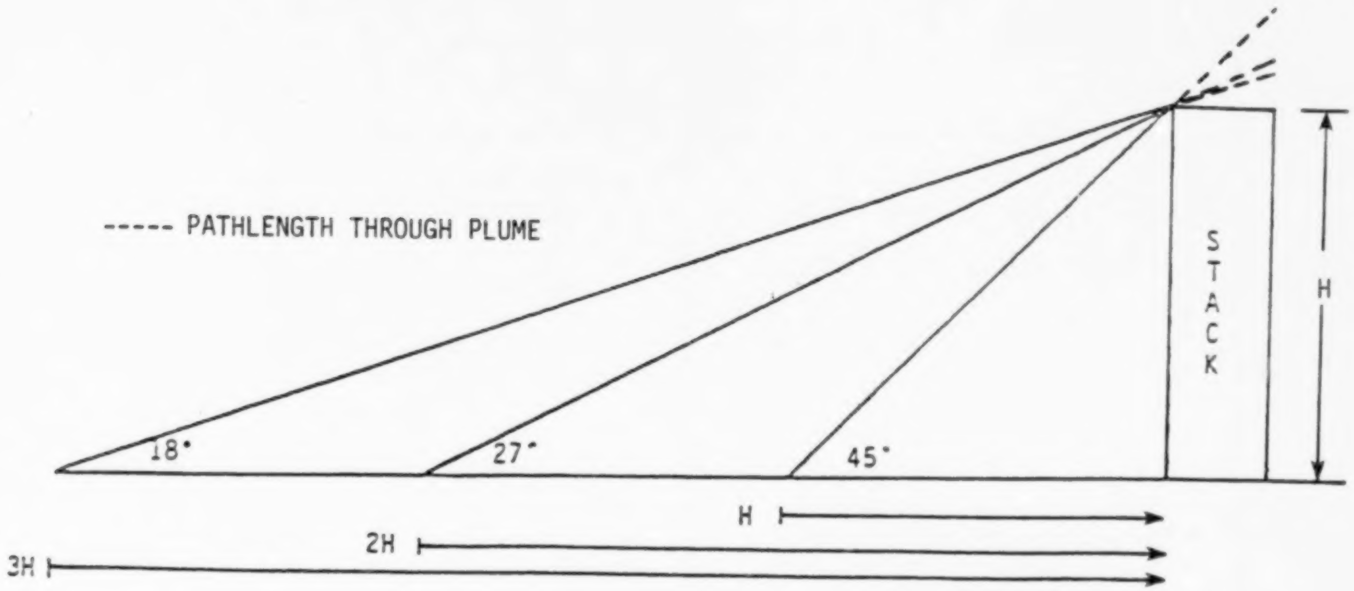

----- PATHLENGTH THROUGH PLUME
S T A C K
H
18°
27°
45°
H
2H
3H

Figure A-2. Variation of pathlength through plume with distance from an elevated source.

The observed pathlength ($P_o$) is calculated as follows:

$$P_o = \frac{D\sqrt{H^2 + Y^2}}{Y}$$

where D = actual width of plume
f = pathlength factor

$$f = \frac{P_o}{D}$$

$$T = 1 - 0 \text{ (decimal form)}$$

where T = transmittance
0 = opacity

$$0_o = 1 - T^f$$

Sample calculation: Y = 2H

$$P_o = \frac{D\sqrt{2^2 + 1}}{2} = \frac{D\sqrt{5}}{2} = 1.12D$$

$$f = \frac{1.12D}{D} = 1.12$$

$$T = 1 - 0.2 = 0.8$$

Thus, $0_o = 1 - 0.8^{1.12} = 22.2\%$

The observer must be close enough to the emission point to have reasonable visual range. Earlier versions of Method 9 recommended that the observer stand a minimum of two stack heights but not further than 0.25 mile from the source. While this is no longer required, it does indicate approximately what distances between the source and the observer are considered optimum.

Background --

Maximum accuracy is obtained when the plume is read against a contrasting background. The reader should choose the background of maximum color contrast with the plume, i.e., a green tree is considered best for a light colored plume and a blue sky for a black plume. Many observers, however, prefer a contrasting object such as a tree or building to be included in the background for all plume readings.

Viewing Point --

Method 9 procedures expressly require that the observation point be that of maximum opacity. This normally means as close to the point of emission as possible since the plume tends to dissipate with travel distance. Exceptions, though, must be made in situations when uncombined water or secondary particulate formation occurs. The observation must be made through a portion of the plume where uncombined water is not present since the water vapor can condense when exposed to cold ambient temperatures and form highly opaque plumes. Always indicate on the observation form where the viewing point is relative to the stack exit or source point.

Time Interval between Readings --

Staring continuously at a reasonably steady state plume while making 15-second interval readings causes eye fatigue, which can result in reduced visual acuity. To prevent this, the observer should only glance at the plume momentarily and make the opacity determination at the regular 15-second intervals. Any deviation from this reading procedure must be noted and explained on the observation form.

Atmospheric Haze --

Both natural or manmade atmospheric haze will generally reduce the contrast between the plume and its background, thereby reducing the opacity reading. Hazy conditions should not significantly affect the opacity reading if the visibility is at least 3 miles.

Wind Speed and Atmospheric Stability --

A strong wind or unstable atmospheric conditions cause rapid dispersion of the plume, thus reducing opacity. As such interferences generally favor the source, this would not hinder official opacity readings. Accurate readings can be made under these conditions as long as the plume remains reasonably intact at the stack exit and as long as the opacity is read as close to the stack exit as possible.

### Night Viewing --

Questions sometimes have been raised about the feasibility of conducting visual opacity observations at night. Plumes can be read accurately at night if special training has been conducted and certain reading conditions exist. The opacity is judged by use of a light as a background target. A few agencies regularly conduct night observations, e.g., Los Angeles Air Quality Mangagement District. Procedures for certification and field observations under nighttime conditions, however, are not addressed in Method 9.

## LECTURE 2: SOURCES OF VISIBLE EMISSIONS

This lecture should be given either by an experienced enforcement person or by an engineer thoroughly familiar with source conditions and opacity reading procedures and problems. The lecture should be illustrated by quality 35-mm slides showing sources and plume conditions commonly seen in field operations.

Opacity readings are generally made in the course of routine source inspections or after a casual observation of apparent visible emissions. Readings can be made either on or off the property of the alleged violator. Observations must, however, be made in conformance with location and viewing conditions conducive to accurate readings, because any field readings and documentation may be used as evidence in a court of law. A source representative may request to be present during the reading period. If that is not possible or desirable, the source should be contacted immediately after the readings are taken to determine the operating conditions during the period of reading. The source may be in a legitimate condition of upset or malfunction, and thus any enforcement action would be unwarranted. The source should be provided the opportunity to explain or defend its operating condition during the period of alleged violation.

The camera is very effective for illustrating the visual appearance of heavy visible emissions. It does not, however, replace accurate opacity observations and can only be used as secondary evidence in court. The inspector can testify that the photograph accurately represents the plume location and geometry that he observed. Care must be exercised in taking photographs so as not to divulge details of processes or operations designated confidential or as proprietary information by the source owner/operator. A telephoto lens should not be used; and if the inspector is on company property, prior permission is required to use a camera.

The observer must also be cognizant of responsibilities and obligations not to inadvertently divulge secret processes or operations in the course of day-to-day inspection or surveillance activities. A source employee might discuss a secret operation or process in order to explain excessive emissions or successful controls, but this privileged information must not be divulged to others.

It is highly recommended that the observer make a perimeter survey prior to and following the observation to determine plant configuration and confirm that multiple plume interaction did not cause inaccurate opacity readings. This initial survey also identifies the most appropriate location with respect to Method 9. Numerous EPA publications and workshops are available on the techniques and procedures for conducting onsite inspection.

## Combustion Sources

Combustion and incineration historically have been the major VE sources. These sources include fuel (primarily coal and oil) combustion for space heating and power generation, incineration for waste disposal or reclamation, mobile sources, and process furnaces or operations.

The principles of combustion (time, temperature, turbulence, and oxygen) should be discussed along with combustion practices that have proven to be successful. Unique conditions and applications for reducing combustion emissions are continually reported by field personnel. An explanation should be presented detailing when emissions are most likely to occur and what can be done to reduce them.

## Noncombustion Sources

Industrial process losses, such as fumes, dusts, mists, gases, and vapors, are classified as noncombustion sources of emissions. Such emissions cannot truly be called "smoke" because this term refers only to the visible effluent resulting from combustion, and consists mostly of soot and fly ash. Operations that emit noncombustion pollutants include grinding, melting, cooking, materials handling, reaction processes, drying, and calcining.

Because a wide variety of industries produce process visible emissions, this lecture should be tailored to the industrial activity where the majority of the attendees will be working. Limit this part of the lecture to a few examples of the problems and techniques involved in identifying, evaluating, and controlling visible emissions from noncombustion sources.

Many VE sources do not fall into the above categories. Some sources such as area and fugitive emissions, may be associated with the source operation. Nonurban sources include demolition, road dust, farming, stockpiles, blasting, quarrying, roof monitors, and perhaps open burning. In urban problem areas, the remaining uncontrolled particulate is emitted from a slightly different set of major sources. Despite the tendency of many agencies not to rely on opacity observations in regulating these sources, the emissions can be accurately read and effectively controlled by opacity regulations. The basic principles of opacity reading apply. The major differences are that opacity is usually read at or near ground level, and the pollutants are not emitted from a confined stack. The biggest problem in reading fugitive emissions is usually defining a single emission point and reading that plume. Some reasonable judgment in that regard will be necessary. Such judgments and conditions of observation must be thoroughly described on the emission form. The stopwatch technique may be preferable in reading some of these source conditions, especially if the plume is intermittent and highly variable. The stopwatch procedure, however, should be stipulated in the applicable regulation.

## Contaminated Water Aerosol Plumes

Plumes containing condensed droplets of water have been variously described as "moist," "wet," "steam," "contaminated water aerosol," or "condensed water vapor" plumes; however, they are usually referred to as "steam plumes." Although this term is not technically correct since steam is a gas, it has become the generally accepted description of a plume containing droplets of condensed water. In a "dry" plume, the temperature remains above the dewpoint and therefore the water remains in the gaseous state with no effect on opacity. As the plume cools and falls below the dewpoint, condensation occurs and water droplets are formed. At this point the visible "steam" occurs. These condensed droplets scatter light, generally causing the plume to appear completely opaque. Because nearly all opacity regulations exempt "steam" or water droplets, care must be exercised to exclude the effect of "steam" in any official plume opacity readings.

The moisture contained in the plume can condense within the stack itself. This plume is generally referred to as an "attached" plume unless the billowing white plume forms downwind of the stack, in which case it is referred to as a "detached" plume. In both cases, the contaminated water aerosol will usually revaporize eventually and then disappear. The formation and disappearance of "steam" are affected by relative temperature and ambient humidity.

Because of the exemption provisions, it is important that the observer readily recognize and discern "steam" contamination. The presence of "steam" in the exit stack gases is determined by the billowy white appearance and the rather rapid dissipation of a dense plume. A dry plume generally does not have the billowy appearance, dissipates very slowly, and diffuses as it travels downwind.

Contaminated water aerosol plumes can be expected from high water consumption processes, wet control systems (e.g., scrubbers and wet electrostatic precipitators), and cooling processes. Therefore, the inspector or observer must have some familiarity with the process and control system in order to expertly assess stack opacity conditions.

## Condensible and Secondary Plume Formations

Both condensible and secondary plume formations are phenomenon of increasing significance and concern, particularly at industrial processes and combustion sources using high-sulfur fuels. Condensible plumes result from condensation of vaporized particulate as plume temperatures decrease. Secondary plumes occur as particulate is formed from reactions of species within the plume. At many sources that have applied high efficiency particulate and sulfur dioxide control systems, a high opacity plume persists.

The major sources of these plumes are fossil fuel-fired power plants, coal-fired cement kilns, wood products drying operations, and Kraft pulp mill recovery furnaces. Secondary formation of condensation products results under certain atmospheric conditions. Under conditions of high humidity, fine sulfuric acid mist particles bind with water molecules from the atmosphere to form large light scattering particles. Such problems are particularly perplexing since industry has spent large sums of money to substantially reduce mass loadings but is still faced with serious opacity control problems.

Another important formation occurs as a result of ambient cooling of the flue gas. Particles of this type (generally organics) are in the vapor state at stack gas temperatures and upon cooling in the ambient air, change to a liquid or solid state. These emissions are often further complicated by so-called steam plumes, and extreme care and keen observation are required to accurately document both condensible and secondary plume formations. The opacity must be read at some distance from the stack, and in this regard, the guidance in Method 9, Section 2.3 is:

> "Opacity observations shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present."

## Other Factors Affecting Plume Opacity

Plume opacity can be significantly affected by a number of factors. The degree of influence of each factor varies widely from source to source. Some of the factors are presented in the following subsections.

### Control Hardware--

The type and performance of particulate control systems can have a significant impact on opacity. Most control devices are highly efficient in collecting large particulates (i.e., > 20 μm), but collection efficiency generally drops with decreasing particle size.

Growing evidence indicates that electrostatic precipitators (ESP's) and wet scrubbers have fractional efficiency curves of the type shown in Figure A-3.

The particles in the 0.2- to 0.5-μm range are particularly difficult to collect due to the limitations of basic physical mechanisms such as impaction and field dependent charging. Consequently, nonideal performance probably leads to the rapid increase in the quantity of 0.2- to 0.5-range emissions. This corresponds to the range that scatters visible light most effectively since the particle diameters are approximately equal to the wavelength of visible light.

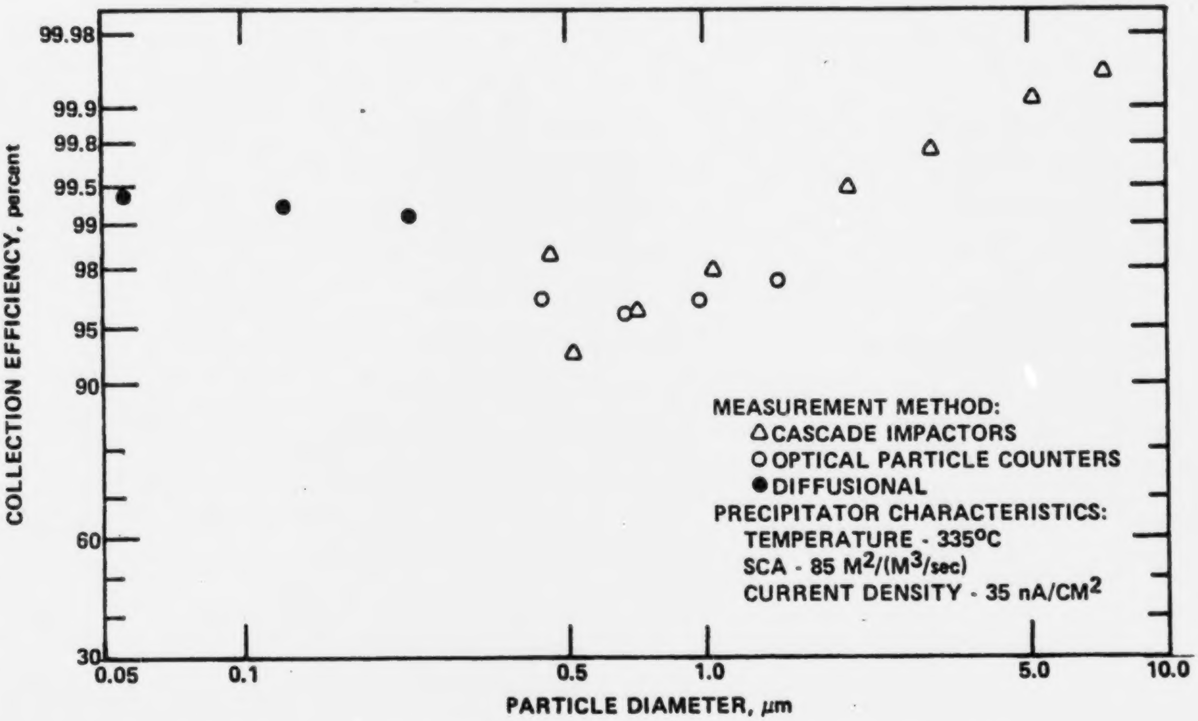


Figure A-3. Measured fractional efficiency of a hot-side ESP installed on a pulverized coal boiler.

Familiarity should be gained with the various control devices and with the variations in system characteristics from source to source. Variations are generally observed and defined over a period of several plant inspections and opacity readings. Therefore, it is important to document and meticulously record one's observations and review the source file and records prior to subsequent inspections and opacity readings.

Process Operation --

Many processes have a cyclic operation (e.g., metallurgical furnace melts). Since visible emissions tend to be highly variable during the cycle, compliance documentation readings should be made during the period when highest opacity emissions are expected. Many source operations (e.g., aluminum plants) have primary and secondary collection systems--collection hoods connected to the primary system and roof monitors connected to the secondary system. The system configurations and the operating conditions during opacity readings should be observed and noted.

Raw Materials --

The quality and content of raw materials can significantly influence particulate emissions. The source of influence can be as simple as the ash content of fuels or as complex as the chemistry of materials and resultant secondary reactions that might increase visible emissions. A well-designed control system may not be compatible with a significant raw material change. This could explain a sudden VE increase and subsequent compliance efforts.

Circumvention --

Most agency regulations address circumvention efforts that are practiced to escape control requirements. Circumvention can be accomplished through multiple stacks, bypasses, diffusers, air dilution, etc. The inspector must be on guard against circumvention efforts or the alternation of operations to produce higher emissions at night or on overcast days, weekends, and holidays.

Atmospheric Conditions --

Wind direction, wind speed, atmospheric stability, turbulence, relative humidity, and several other meteorological parameters influence the appearance of the plume. The wind direction affects the orientation of the observer and the plume. Plumes blown directly toward or away from'the observer generally result in readings through longer pathlengths through the plume than those observed when the wind blows perpendicular to the observer's line of sight. The longer the pathlength through the plume, the higher the apparent plume opacity. As is the case with unstable atmospheric conditions, stronger winds increase dilution and thus reduce opacity.

Miscellaneous Factors --

Other factors that can influence opacity reading include background, sun angle, observer distance, and visual aids such as sunglasses. Therefore, it is important that these conditions and their respective influences be extensively documented before, during, and after the readings on the observation report.

## LECTURE 3: FIELD OPERATIONS

This section discusses the proper procedures for conducting field inspections. This presentation should be made by an experienced field inspector or engineer.

Making technically sound opacity readings requires adequate preparation. In addition to being currently certified, the reader must know the source. This preparation requires review of the official source file to determine process operating conditions, type and location of control equipment, history of any VE problems, possible observation sites, applicable regulations, presence of condensed water vapor plumes, pertinent operating data, and names of contact, etc.

An opacity reader should have adequate supplies and equipment, including inspection forms, writing pad or surface, field logs, stopwatch, sling psychrometer, range finder, compass, binoculars, and camera. It is recommended that field personnel always be equipped with a hard hat, safety boots, safety goggles, and in some instances, coveralls and a respirator. Other equipment that may be necessary depending on the type of source and the observation conditions includes topographic maps and a hand-held anemometer. In some instances, agency field personnel have conducted observations with little, if any, of this equipment, and data frequently have been recorded on a standard note pad, without the aid of even a watch. The field personnel must be adequately equipped and familiar with the use of all equipment. Fully acceptable readings, however, can be made pursuant to Method 9 with only a watch and proper forms. The remainder of the equipment simply makes the inspector's job more convenient, and does not necessarily render the observation more accurate.

An agency-approved standard opacity form is essential to the quality assurance of an enforcement program. This form assures that all proper data will be obtained and recorded to document accurate readings and it assures better consistency of technique and information reported by different readers. The consistency and adequacy of documentation should be reviewed and verified by the supervisor or legal personnel prior to initiating enforcement actions.

The reading data must be reduced or summarized in accordance with applicable regulations. Thus, if an NSPS source is involved, at least 6 minutes of observation must be recorded to obtain an average of 24 individual consecutive readings. In some instances where more than one regulatory provision might apply, the readings could be reduced by frequency count, averaging, and/or time accumulation, with the more stringent provision taking precedent.

The need for thorough and accurate field notes should be reemphasized. Any field observation is fresh and clear in one's mind shortly after the reading; most enforcement actions, however, happen after a considerable lapse of time, perhaps years. Hurried or sketchy notes can jeopardize the quality and credibility of such enforcement actions.

Agency staff should make a copy of the observations available to source personnel by leaving a carbon copy or by later mailing a copy from the office, depending on agency policy. This should be done with minimum delay and should be officially noted in the record of action. Preferably, a representative of the source should sign the front of the observation form to acknowledge receipt. Under no circumstances, though, should the inspector attempt to summarize the results as a finding of noncompliance or compliance. This is a conclusion of law and the inspector's domain is limited to conclusions of fact. In addition, such action would preempt the inspector's supervisor and agency legal staff.

## LECTURE 4: AIR POLLUTION METEOROLOGY

Meteorology has a large influence on air quality. This impact can be from the microscale of building turbulence to the macroscale of pressure systems. Several meteorological parameters directly influence plume opacity (wind speed and direction, humidity, cloud cover, atmospheric haze, etc.). The field inspector must be aware of these factors and their potential impact on opacity readings.

Although air pollution meteorology can be quite complex, especially the mechanics and mathematics that pertain to diffusion or dispersion modeling, the opacity reader should be familiar with meteorological concepts. This lecture should be given by an air pollution meteorologist, a specialist who can present the material with a practical application. The lecture content should describe the basic plume behavior (Figure A-3) and its formation and associated meteorological conditions (Table A-3).

Plume behavior and transport (vertical and horizontal) are largely a function of atmospheric stability and lapse rate and should be reasonably understood by the opacity observer. Of more direct influence in making quality opacity readings are relative humidity, wind speed, cloud cover, sky contrast, etc. Several techniques can be used to measure or estimate these conditions.

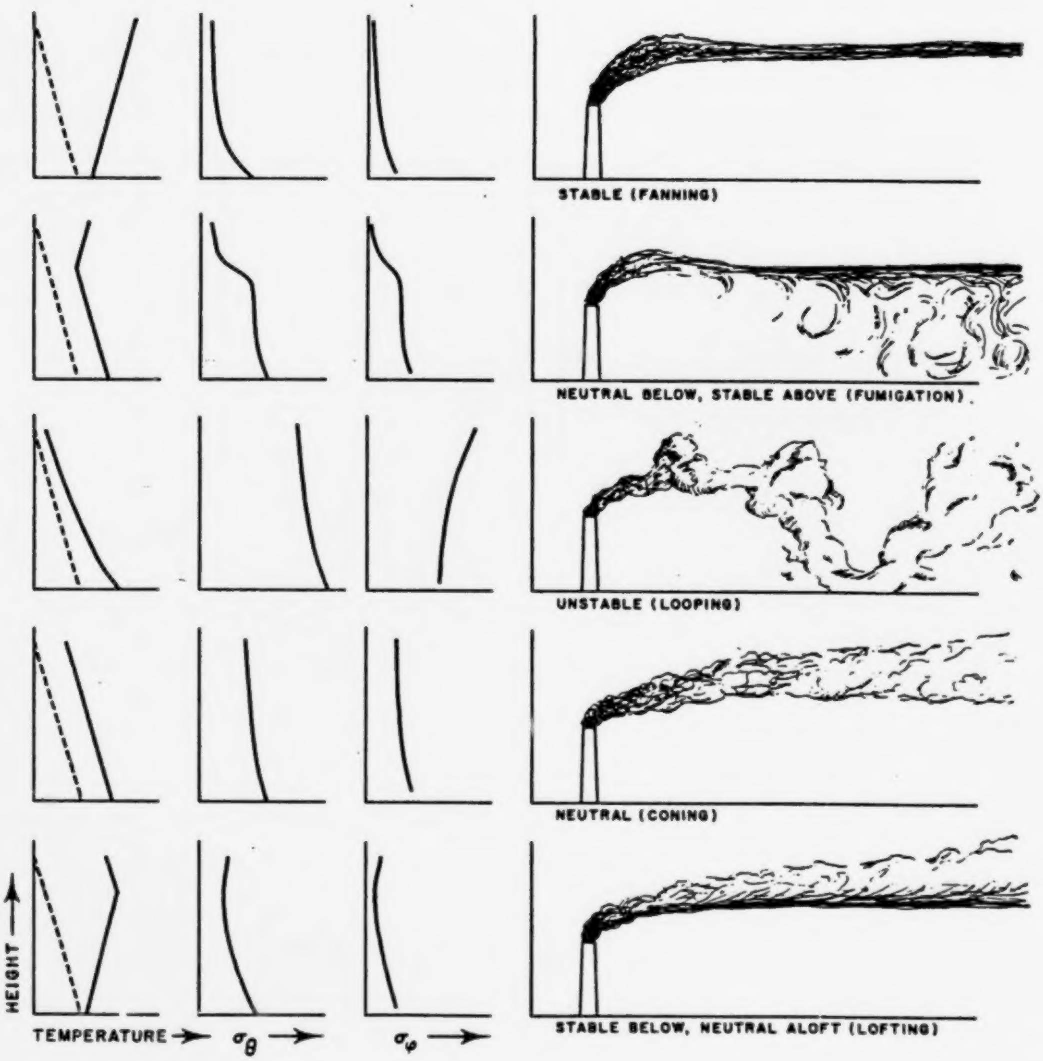

STABLE (FANNING)
NEUTRAL BELOW, STABLE ABOVE (FUMIGATION)
UNSTABLE (LOOPING)
NEUTRAL (CONING)
STABLE BELOW, NEUTRAL ALOFT (LOFTING)
HEIGHT
TEMPERATURE
$\sigma_\theta$
$\sigma_\varphi$

Figure A-3. Basic plume behavior.

TABLE A-3. PLUME BEHAVIOR AND RELATED WEATHER

| Description of visible plume | Typical occurrence | Meteorological conditions | Dispersion and ground contact |
|---|---|---|---|
| Fanning | | | |
| Narrow horizontal fan; little or no vertical spreading; if stack is high, resembles a meandering river, widening but not thickening as it moves along; may be seen miles downwind; if effluent is warm, plume rises slowly, then drifts horizontally | At night and in early morning, any season; usually associated with inversion layer(s); favored by light winds, clear skies, and snow cover | Inverted or isothermal lapse rate; very stable; light winds; very little turbulence | Disperses slowly; concentration aloft high at relatively great distance downwind; small probability of ground contact, though increase in turbulence can result in ground contact; high ground level concentrations may occur if stack is short or if plume moves to more irregular terrain |
| Fumigation | | | |
| Fan or cone with well defined top and ragged or diffuse bottom | During change from inversion to lapse condition; usually nocturnal inversion is broken up through warming of ground and surface layers by morning sun; breakup commonly begins near ground and works upward, less rapidly in winter than in summer; may also occur with sea breeze in late morning or early afternoon | Adiabatic or superadiabatic lapse rate at stack top and below; isothermal or inverted lapse rate above; lower layer, unstable or neutral, upper layer stable; winds light to moderate aloft, and light below; thermal turbulence in lower layer, little turbulence in upper layer | Large probability of ground contact in relatively high concentration, especially after plume has stagnated aloft |

(continued)

TABLE A-3 (continued)

| Description of visible plume | Typical occurrence | Meteorological conditions | Dispersion and ground contact |
|---|---|---|---|
| Looping | | | |
| Irregular loops and waves with random sinuous movements; dissipates in patches and relatively rapidly with distance | During daytime with clear or partly cloudy skies and intense solar heating; not favored by layer-type cloudiness, snow cover or strong winds | Adiabatic or superadiabatic lapse rate; unstable; light winds with intense thermal turbulence | Disperses rapidly with distance; large probability of high concentrations sporadically at ground relatively close to stack |
| Coning | | | |
| Roughly cone-shaped with horizontal axis; dissipates farther downwind than looping plume | During windy conditions, day or night; layer-type cloudiness favored in day; may also occur briefly in a gust during looping | Lapse rate between dry adiabatic and isothermal; neutral or stable; moderate to strong winds; turbulence largely mechanical rather than thermal | Disperses less rapidly with distance than looping plus large probability of ground contact some distance downwind; concentration less but persisting longer than that of looping |
| Lofting | | | |
| Loops or cone with well defined bottom and poorly defined, diffuse top | During change from lapse to inversion condition; usually near sunset on fair days; lasts about an hour but may persist through night | Adiabatic lapse rate at stack top and above; inverted below stack; lower layer stable, upper layer neutral or unstable; moderate winds and considerable turbulence aloft; very light winds and little or no turbulence in layer below | Probability of ground contact small unless inversion layer is shallow and stack is short; concentration high with contact but contact usually prevented by stability of inversion layer; considered best condition for dispersion since pollutants are dispersed in upper air with small probability of ground contact |

Relative humidity is measured by a psychrometer, following a simple procedure. If this instrument is not available, an adequate reading can, in most instances, be obtained from airports, weather stations, or perhaps a local TV station. High humidity days (≥ 70 percent) are usually associated with atmospheric turbidity that can interfere with accurate opacity readings.

Wind direction is determined readily by the direction of plume travel in relation to the orientation of the compass. Wind speed can be measured by a small rotameter or hand-held anemometer. Area wind information can be obtained for the period in question from the local weather station. A reasonable estimate of wind speed can also be made by use of the Beaufort scale. Accurate determination of wind speed is not as important as other measurements. It is basically important to support that reasonable readings were, in fact, possible and that unusual turbulence and plume shearing or separations were not occurring.

## LECTURE 5: LEGAL ASPECTS

This lecture should be presented by an attorney thoroughly familiar with the practice and problems of air pollution control enforcement as well as those recent court decisions that have affected the field of opacity reading. It is becoming increasingly important that all field opacity readings be conducted with the approach and attitude that the documentation must withstand the rigors of court scrutiny and interrogation. Because the evidence is only as strong as the weakest element, it is important that all aspects of the program (from classroom training and certification to field readings and documentation) be conducted within the requirements and structure of a good quality assurance program. This requires the field observer to have thorough training and to be familiar with the legal requirements and conditions.

As the frequency and amount of fines and penalties increase, industry is growing more concerned about the significance of a technically and legally sound opacity enforcement program. Opacity readings by field observers account for more than 90 percent of agency enforcement actions. In response, industry is spending a great deal of money to better understand the theory and practice of opacity reading. Industry has also initiated several precedent-setting legal actions to weaken this important tool. Therefore, an understanding of the legal requirements and cases is essential to avoid needless jeopardy in important enforcement actions.

## Applicable Regulatory Provisions

Field readings made by the opacity observer will usually document compliance or noncompliance with several levels or layers of regulatory provisions. To help identify and promote the required understanding of the applicable provisions, the more common regulatory requirements are listed below:

Clean Air Act, as Amended 1977 --

Section 110 - State Implementation Plan Requirements
Section 111 - New Source Performance Standards
Section 112 - Emission Standard for Hazardous Air Pollutants
Section 113 - Federal Enforcement Authority
Section 114 - Inspection, Monitoring, and Entry
Section 119 - Nonferrous Smelter Orders
Section 120 - Noncompliance Penalty
Section 160 - Prevention of Significant Deterioration
Section 169 - Prevention of Significant Deterioration (Section A)
Section 303 - Emergency Powers

State Air Pollution Control Laws and Regulations --

Nearly all states have opacity emission regulations that must be at least as stringent as those of the applicable Federal regulations. States are generally adopting Federal regulations (i.e., NSPS) but omissions and even inconsistencies may be discovered. Therefore, it should be remembered that several opacity emission regulations may apply to VE control for any pollutant source.

Local Laws, Ordinances, and Regulations --

Familiarity should be gained with these regulations which, in some cases, are more stringent than State or Federal regulations.

## Important Legal Cases

Opacity observations as a viable enforcement tool have been repeatedly upheld by several state courts as well as the U.S. Supreme Court. Significant court cases concerning opacity as a viable enforcement tool are reviewed in several references listed below. Opacity standards have withstood the rigors of many serious challenges in the courts of this country. Recent rulings include:

1. Air Pollution Variance Board of the State of Colorado v. Western Alfalfa Corporation, 419 U.S. 815, 94 S. Ct. 2114 (1974), at footnote 1.
2. State of New Jersey v. Fry Roofing Co., Docket No. C-3682-72 (N. J. Superior Court, 1974, attached as Appendix A).
3. St. v. Fry Roofing Co., 495 F. 2d 751, 4 ERC 1116 (Ore. Ct. of App. 1972).
4. People v. Plywood Manufacturers, 291 P. 2d 587 (Sup. Ct. of Los Angeles, Ca. 1955). California enacted a statutory opacity requirement as early as 1947. Cal. Health and Safety Code 24242.
5. Essex Chemical Corp. v. Rickelshaus, 158 U.S. App. D.C. 360, 486 P. 2d 427 (1973).
6. Portland Cement Association v. Rickelshaus, 486 F 2d 375, U.S. Court of Appeals, District Columbia Circuit (June 29, 1973).

The following court cases established important legal precedents that are significant to the conduct of a sound enforcement program.

The case of Air Pollution Variance Board (Colorado) v. Western Alfalfa Corporation, No. 73-690, U.S. Supreme Court, May 20, 1974, pointed out the necessity of immediately notifying the source where opacity readings had documented a violation. The Court ruled that the source management must have opportunity to defend itself, and that it is unreasonable to expect the source representation to reconstruct in court the operating conditions on the day of the opacity observation several days or months later as an explanation of the observed excessive emissions.

The case of Donner-Hanna Coke Corporation v. Administrator U.S. EPA, Civil Action No. 77-232, in the U.S. District Court for New York, January 1978 pointed out the necessity of having clearly defined procedures in opacity documentation. The court ruled that EPA was remiss in not having documented the applicability and accuracy of the "stopwatch" reading method.

## Legal Procedures

The inspection/enforcement staff must work closely with the legal staff. Before referring the case to the attorney, the field observer and supervisor should review the evidence and soundness of the opacity readings. The attorney should review the evidence again and thoroughly discuss any evidence of possible case weakness. Corrective actions (such as additional field readings) should be taken if possible. These tier level reviews provide a final layer of QA review to the enforcement action.

The attorney and enforcement staff should again review the applicable regulatory provisions and be cognizant of any duplicate opacity regulations (i.e., State Implementation Plan, NSPS and Prevention of Significant Deterioration provisions). The legal staff will probably decide if the case is to be prosecuted as a civil or criminal action. The inspector should have a reasonable understanding of each procedure and his/her role as an expert witness. The film "Role of the Witness" illustrates proper presentation and behavior in this role.

## Legal Restraints

Different types of sources and different areas of the country require different VE restrictions. Certain operations may be exempt from the regulations, and exceptions may be allowed for others (such as agricultural burning) during certain periods of time. The specific variances applicable to the course location should be discussed.

## Authority to Enter Facilities

Section 114 (a) 2 of the Clean Air Act duly authorizes the control official to enter any facility to make inspections, take samples or readings, and gather information and records. Similar authorization is contained in the enabling authority of most or all states. This authority, however, is being subjected to frequent challenges. Any inspector denied entry should seek assistance from his/her supervisor and agency attorney to obtain a search warrant.

## Signing Waivers

It is a fairly common practice for companies to request nonemployees or visitors to sign liability waivers as a condition of entry onto their industrial facilities. EPA employees cannot be denied entry for refusal to sign such waivers, and are specifically instructed not to sign such statements. To sign such waiver statements could jeopardize the rights of the individual and his/her employer in cases of unforeseen injury or damage.

### Confidential Information

In order to explain excessive emissions, the company may divulge or share confidential information. It is important to understand the liability associated with such information and the precautions that must be taken to protect it. Further decisions and guidance are presented in 40 CFR Part 2, Public Information.

## LECTURE 6: TESTING PROCEDURES

The preceeding classroom lectures have built the foundation for this lecture. The student should now be familiar with the theory, history, source conditions, meteorology, and reading techniques. The next step is to work with the smoke generator to "calibrate" the eyes and develop a proficiency and confidence for making field readings.

The trainee must be fully informed and aware of the events and procedures in field training. The training supervisor or assistant will be in charge of this portion of the training. Most instructors have found 35-mm slides helpful in presenting the material and in displaying the generator equipment and components. High-quality slides can effectively simulate smoke in increments of 10 or 20 percent opacities.

Practice forms may be distributed to the class, and practice recordings may be referenced to assure the skillful completion of the forms. Needed field equipment should be listed: clipboard, ballpoint pens, comfortable clothing, and folding chair. The class should be told that any trainee who intends to wear sunglasses in training and certification must wear the same type of glasses when making field opacity readings. Glasses that change intensity with changing sunlight and those with nonstandard colors are not recommended. The best sunglasses for opacity reading are those with gray and green tints.

The trainees should be reminded of the time and location for the field testing and certification.

## Quiz

A short quiz should be given at the conclusion of the classroom series for two reasons. First, the quiz will indicate the trainee's comprehension of the material offered in the lectures. The test need not pose an obstacle to the student, but simply indicate whether the student understands the key points of the lectures. Problems with specific questions would indicate that this particular material has not been clearly presented. It may be possible to clarify important points or at least make adjustments for subsequent sessions and provide a QA check on the training effectiveness.

Second, the last few questions on the quiz would allow a brief critique of the course. These questions would alert the instructor to any parts of the lecture that need improvement. Both the quiz and critique will provide information to allow the instructor to continually improve the training program. Two sample quizzes are provided in Figures A-5 and A-6.

NAME______________________________

DATE______________________________

LOCATION__________________________

## SMOKE SCHOOL QUIZ

1. A certificate is valid for:

   A. 6 months B. 1 month C. 1 year

2. The observer should stand,

   A. facing the sun B. with the sun at his back C. With the sun at his side

3. The opacity scale is used for

   A. Black smoke B. White smoke C. Red smoke D. Blue smoke

   E. A & B F. All of the above

4. A North wind blows from

   A. South B. North C. West D. East

5. The smoke reading shall be taken with no allowance for deviation

   A. At the top of the stack B. At the top of the plume

   C. At the widest part of the plume D. At the narrowest portion of the plume

   E. At the densest portion of the plume

6. Smoke reading is a/an ______________________ measurement.

   A. Objective B. Subjective

7. The following is not a part of white smoke generation equipment:

   A. Toluene B. Fuel pump C. Gasoline engine D. Blower

8. The following is not a part of black smoke generation equipment:

   A. Gasoline engine B. Toluene C. Fuel pump D. Blower

9. White smoke emitted from the generator consists of:

   A. Talcum powder B. Oil soot C. Oil vapor D. Steam

Figure A-5. Sample Smoke School Quiz I.

(continued)

Figure A-5 (continued)

Short answer or listing.

10. Define opacity.

11. What are the advantages of the visual method of plume evaluation?

12. What are the limitations of visual plume evaluation?

13. Sketch the proper relationships of (A) Smoke Reader, (B) Stack, (C) Wind direction (use plume), and (D) Sun's position (indicate North).

14. What color light is most visible to human eyes? ______________________
Why is this important?

15. What are light obscuring mechanics?

16. What is a hold harmless agreement?

17. What should be added to this course?

18. What should be removed?

19. What should receive extra emphasis?

Name ______________________________

1 point

SMOKE SCHOOL QUIZ

Multiple Choice - 3 points each

1. A certificate is valid for:
   A. 6 months B. 1 month C. 1 year
2. The observer should stand:
   A. Facing the sun B. With the sun on his back C. With sun at his side
3. The opacity scale is used for:
   A. Black smoke B. White smoke C. Red smoke D. Blue smoke
   E. A & B F. All of the above
4. A North wind blows from the:
   A. South B. North C. West D. East
5. The smoke reading shall be taken:
   A. One stack diameter above the top of the stack
   B. At the top of the plume
   C. At the widest part of the plume
   D. At the narrowest part of the plume
6. The plume axis should be:
   A. Along the reader's line of sight B. At right angle to the reader's line of sight
7. Smoke reading is a/an ____________________ measurement.
   A. Objective B. Subjective
8. White smoke emitted from the generator consists of:
   A. Talcum powder B. Oil soot C. Oil vapor D. Steam

Figure A-6. Example Smoke School Quiz II.

(continued)

Figure A-6 (continued)

Matching - 1 point each

9. _____ 20% opacity
10. _____ 0% opacity
11. _____ Water vapor
12. _____ 50% opacity
13. _____ Gaseous pollutants
14. _____ Wind speed
15. _____ 80% opacity
16. _____ Light scattering
17. _____ Photocell
18. _____ Neutral density filter
19. _____ 100% opacity

A. Transmissometer
B. Not measurable
C. 0 Ringelmann
D. 2½ Ringelmann
E. Steam Ringelmann
F. 5 Ringelmann
G. 4 Ringelmann
H. Calibration
I. 1 Ringelmann
J. Beaufort scale
K. Opacity

Short answer or listing - 8 points each

20. What is opacity (25 words or less)?

21. What are the advantages of the visual method of plume evaluation?

22. What are the limitations of visual plume evaluation?

23. Distinguish combustion versus process sources.

24. How can photographs be useful in smoke reading?

25. List typical sources of BLACK smoke.

Figure A-6 (continued)

26. List typical sources of WHITE smoke.

27. What is a sling psychrometer?

28. What changes would you recommend to improve the lecture content?

29. Were speakers adequately prepared?

30. Were classroom facilities generally adequate? If not, what changes would you recommend?

# APPENDIX B

## PERFORMANCE AUDIT AND SYSTEM AUDIT

This appendix provides an example grading and recordkeeping checklist for field certification test performance audits (Table B-1), a checklist for smoke generator performance audits (Table B-2), and an extensive information checklist for a smoke school training and certification system audit (Table B-3). These forms are designed to check and document QA for visible emissions training programs.

## TABLE B-1. GRADING AND RECORDKEEPING CHECKLIST FOR PERFORMANCE AUDIT OF FIELD CERTIFICATION TESTS

Agency ______________________ Date ______________________

Operator ______________________ Location ______________________

Auditor ______________________

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| Field Operations | | | |
| Certification forms (carbon/NRC paper) | | | |
| Field certification forms distributed individually to participants by field certification test supervisor | | | |
| Participants instructed to sign completed form before separating copies | | | |
| Participants instructed to submit original, completed, signed form to test supervisor | | | |
| Forms reviewed by supervisor for name, signature, illegible characters, completeness | | | |
| Completed forms checked against list of participants; discrepancies noted | | | |
| Both forms filed in a secure area | | | |
| Strip chart reviewed for correctness by test supervisor and smoke generator operator | | | |
| Operator certified that test completed in accordance with provisions of Method 9; noted on chart | | | |

(continued)

TABLE B-1 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Chart with test forms and participant list secured by test supervisor | | | |
| Office Operations<br>Master opacity sheet from strip chart audited for correctness | | | |
| Forms checked against participant list | | | |
| Certification forms graded; mean and maximum deviations noted against master opacity sheet; name, statistics, and pass/no pass recorded on standardized grading form | | | |
| Opacity readers with mean deviation $\leq$ 7.5% and no deviation > 15% passed by grader | | | |
| Grading of certification form, and pass/no pass status reviewed by checker/auditor | | | |
| Test forms, grading form, class list, strip chart and master opacity chart forwarded to training coordinator; accuracy of grades and pass/no pass status certified | | | |
| Certificates to passing students issued by training coordinator in accordance with school requirements and 6-month certification period | | | |
| Test forms, grading forms, class list, strip chart, master opacity list, and list of certified readers filed in secure area by training coordinator | | | |

## TABLE B-2. SMOKE GENERATOR FOR CHECKLIST PERFORMANCE AUDIT

Agency ______________________ Date ______________________

Operator ______________________ Location ______________________

Auditor ______________________

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| Pre-Setup Inspection | | | |
| General damage or damaged components checked | | | |
| Inventory of parts and supplies completed | | | |
| Fans and motors lubricated | | | |
| Console received preliminary check | | | |
| If transmissometer not inspected within last 6 months: | | | |
| Transmissometer disassembled and inspected | | | |
| Photocell detector inspected for alignment, damage, and proper electrical connection | | | |
| Phototopic response required by photocell | | | |
| Angles of projection and view $\leq$ 15 degrees | | | |
| Standard Fuels Used | | | |
| Toluene | | | |
| Diesel or fuel oil | | | |
| Propane | | | |
| Other (specify kind and use) | | | |

(continued)

TABLE B-2 (continued)

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| Generator Setup | | | |
| Background, sky, and wind conditions checked for best generator orientation | | | |
| Generator leveled and wheels chocked | | | |
| Separate control console set up | | | |
| Checks conducted for fuel leaks (lines, connections and tanks) | | | |
| Fans | | | |
| All fans checked for smooth, normal noise level | | | |
| Main or induced draft fan checked for normal operation and flow rate | | | |
| Transmissometer fans checked for normal operation | | | |
| Operation of the Generator | | | |
| Generator logbook available and used | | | |
| Both fuel pumps operable and not leaking | | | |
| Chart recorder paper supply adequate for proposed runs | | | |
| Chart recorder visible to operator or assistant | | | |
| Chart recorder equipped with event marker or otherwise easily marked by operator or assistant | | | |

(continued)

TABLE B-2 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Console allowed to warm up for 30 minutes before making opacity measurements | | | |
| All opacity readout systems operational, stable, and consistent | | | |
| Transmissometer System Calibration<br>Initial zero and span drift check completed; repeated after each run | | | |
| Drift greater than 1% corrected | | | |
| Response time checked prior to testing; 0 to 100% opacity swing | | | |
| Response time 0 to 100%, ≤ 5 seconds | | | |
| Light source voltage checked prior to testing | | | |
| Voltage ± 5% of nominal | | | |
| Calibration check<br>Filters within ± 2% of nominal value<br>Five (nonconsecutive) checks for each filter completed<br>Maximum error, 3% opacity<br>Calibration record completed | | | |

(continued)

TABLE B-2 (continued)

| Activity check | Adequate |  | Comments/corrective action |
|---|---|---|---|
|  | yes | no |  |
| Generation of Smoke<br>Black smoke stability and range test complete |  |  |  |
| Opacity range 0 to 100% for black smoke |  |  |  |
| White smoke stability and range test complete |  |  |  |
| Opacity range 0 to 100% for white smoke |  |  |  |
| Public Address System<br>Setup and operation checked |  |  |  |
| Voice and cuing horn audible and clear throughout reader area |  |  |  |
| Total smoke system calibrated and operating properly for training and certification purposes |  |  |  |

Comments (please list any problems or conditions encountered in the setup or startup of the smoke generator):

Auditor's signature ____________________

Date ____________________

## TABLE B-3. SMOKE SCHOOL TRAINING AND CERTIFICATION SYSTEM AUDIT

I. General Information

Agency________________________ Date________________________

Address________________________

________________________

Smoke School Personnel

Training Supervisor______________________ Phone______________

Smoke Generator Operator______________ Phone______________

Training Assistants______________________ Phone______________

______________________ Phone______________

Organization Schematic

Schedule of Training/Certification (year _____)

Classroom ___________, ___________, ___________

Field opacity _____, _____, _____, _____, _____, _____, _____, _____

Average Number of Students Trained (year ____)

Agency ___________ Industry ___________

Other (specify) ______________________________________________

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| II. Classroom Training | | | |
| A. Registration and Orientation | | | |
| Forms and records | | | |
| Procedure | | | |
| B. Theory and Principles of Opacity Reading | | | |
| Visual aids | | | |
| Materials and Preparation | | | |
| Definition of opacity | | | |
| Opacity vs. transmissometer | | | |
| Contracts and background effect | | | |
| Particle size | | | |
| Chemical and physical properties | | | |
| Light scattering | | | |
| C. Sources of Visible Emissions | | | |
| Visual aids | | | |
| Material and Preparation | | | |
| Combustion sources | | | |
| Noncombustion sources | | | |
| Fugitive sources | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Plume characteristics | | | |
| Identifying water vapor | | | |
| Effect of control equipment | | | |
| D. Opacity Reading and Field Documentation | | | |
| Visual aids | | | |
| Materials and preparation | | | |
| Techniques of reading opacity | | | |
| Standardized forms and field log | | | |
| Important parameters | | | |
| Field equipment | | | |
| Regulations | | | |
| Source review | | | |
| Reading location | | | |
| Sun angle | | | |
| Number or time of readings | | | |
| Data reduction | | | |
| Contacting the source | | | |
| E. Meteorology | | | |
| Visual aids | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Materials and preparation | | | |
| Atmospheric stability | | | |
| Relative humidity | | | |
| Plume characteristics | | | |
| Wind speed and direction determinations | | | |
| Building and obstruction effects | | | |
| Cloud cover | | | |
| F. Legal Aspects | | | |
| Visual aids | | | |
| Material and preparation | | | |
| Legal history | | | |
| Legal precedents | | | |
| Right of entry | | | |
| Hold harmless agreement | | | |
| Free and open field concepts | | | |
| Evidence and source information disclosure | | | |
| Freedom of information | | | |
| Case preparation | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Requirements of certification | | | |
| Expert witness | | | |
| G. Preparing for Testing and Certification | | | |
| Visual aids | | | |
| Materials and preparation | | | |
| Requirements for certification | | | |
| Review techniques for reading opacity | | | |
| Forms | | | |
| Calibrating the eye | | | |
| When to read | | | |
| Use of glasses or other aids | | | |
| H. Closing | | | |
| Course review | | | |
| Quiz | | | |
| Discussion | | | |
| I. Refresher Courses | | | |
| Requirements | | | |
| Frequency | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| J. Presentation and Preparation | | | |
| Background speeches | | | |
| Speaker experience | | | |
| Material organization | | | |
| Preprinted notes and illustrations | | | |
| Visual aids | | | |
| K. Facilities and Training Equipment | | | |
| Classroom | | | |
| a. Size and suitability | | | |
| b. Comfort and convenience | | | |
| Visual aid equipment | | | |
| Chalkboard, easel, etc. | | | |

III. Field Training and Certification

A. Site Selection

| | | |
|---|---|---|
| Smoke generator power supply | | |
| Suitable backgrounds for reading smoke | | |
| Sufficient area for expected number of readers | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| Reader and generator properly oriented with sun | | | |
| B. Smoke Generator | | | |
| General condition and operability | | | |
| Operating manual | | | |
| Transmissometer system[a] | | | |
| Angle of projection (15° max) | | | |
| Angle of view (15° max) | | | |
| Photopic response | | | |
| Incandescent light source | | | |
| Nominal rated voltage (± 5%) | | | |
| Calibration filters (± 2%) | | | |
| Calibration error (± 3%) | | | |
| Ease of calibration | | | |
| Zero and span drift (± 1%) | | | |
| Response time (max 5 sec) | | | |
| Transmissometer fans | | | |
| Controls (operating and identified) | | | |
| Readout devices (specify type) | | | |
| | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Control Panel | | | |
| Operating condition | | | |
| Operability | | | |
| Controls identified | | | |
| Electrical/fuel connections | | | |
| Main Fan | | | |
| Capacity (cfm) | | | |
| Air flow control | | | |
| Stack | | | |
| Diameter (12" minimum) | | | |
| General condition | | | |
| Raising/lowering mechanism | | | |
| Black Smoke Generation | | | |
| Fuel supply and type | | | |
| Stability of plume opacity | | | |
| Capable of generating 0 to 100% opacity | | | |
| Color of smoke over opacity range | | | |
| Safety of operation | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| White Smoke Generation | | | |
| Fuel supply and type | | | |
| Stability of plume opacity | | | |
| Capable of generating 0 to 100% opacity | | | |
| Safety of operation | | | |
| General | | | |
| Spare parts inventory | | | |
| Maintenance tools | | | |
| Maintenance log | | | |
| Operations procedural manual | | | |
| Operator protected during inclement weather | | | |
| Public Address System | | | |
| Audible in reader area | | | |
| Bell or buzzer for cuing | | | |
| IV. Operation of Smoke Generator | | | |
| Operators familiar with the operation of the equipment | | | |
| Generator service and maintenance conducted | | | |

(continued)

TABLE B-3 (continued)

| | Adequate | | |
|---|---|---|---|
| Activity check | yes | no | Comments/corrective action |
| Generator checked for operation prior to day of training and certification | | | |
| Warmup before operation prior to day of training and certification | | | |
| Calibration requirements completed | | | |
| Data and information properly recorded and maintained | | | |
| Students provided reasonable training at selected opacity levels | | | |
| V. Certification Testing | | | |
| A. Meeting Method 9 Requirements | | | |
| Both 25 white and 25 black readings on one sheet | | | |
| No more than 7.5% average opacity deviation accepted on either the white run of 25 or the black run of 25 | | | |
| No error exceeding 15% opacity allowed | | | |
| Points of test given in random order | | | |
| Applicants required to certify from the correct viewing angle | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Applicants properly instructed before testing | | | |
| Adequate communication between tester and teacher | | | |
| Standards provided prior to tests | | | |
| Background provided | | | |
| Smoke held at one value long enough for evaluation | | | |
| Weather conditions considered | | | |
| Elbow used during windy periods | | | |
| B. Testing Forms | | | |
| Carbon or NCR | | | |
| Name | | | |
| Location | | | |
| Date | | | |
| Run and color identification | | | |
| Distance from stack | | | |
| Sun/stack reader orientation | | | |
| Time of day | | | |
| Cloud cover | | | |
| Wind speed | | | |
| Wind direction | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate | | Comments/corrective action |
|---|---|---|---|
| | yes | no | |
| Sunglasses (type) | | | |
| Corrections noted | | | |
| Student signature | | | |
| Graded by | | | |
| Validated by | | | |
| C. Issuance of Cards and/or Certification | | | |
| Dated properly | | | |
| Accountable forms | | | |

VI. Quality Assurance

| | | | |
|---|---|---|---|
| A. Records Control (Retained for 5 yrs by agency) | | | |
| Student lists | | | |
| Transmissometer calibration data | | | |
| Transmissometer opacity data | | | |
| Student test forms | | | |
| Issued certificates | | | |
| B. Auditing Functions | | | |
| Traceability of calibration standards | | | |
| Calibration of generator transmissometer | | | |
| Auditing of generator transmissometer data | | | |

(continued)

TABLE B-3 (continued)

| Activity check | Adequate yes | Adequate no | Comments/corrective action |
|---|---|---|---|
| Verification and control of documentation | | | |
| Auditing of grading system | | | |
| Performance audits conducted | | | |
| C. Maintenance of Control Statistics | | | |
| Standards | | | |
| Transmissometer response | | | |
| Reported opacity | | | |
| Applicants final test score | | | |
| Percent certification | | | |
| Other | | | |
| Calculated according to accepted statistical methods | | | |
| D. General Information (specify numbers) | | | |
| Number of schools per year | | | |
| Number of persons per school | | | |
| Number of recertifiers | | | |
| Percentage of new applicants certifying | | | |
| Percentage of recertifiers certifying | | | |

---

[a] The transmissometer system consists of the light source, photocell, fans, and readout instruments. The system must meet applicable 40 CFR 60, Appendix A, Method 9 specifications.

# APPENDIX C

## ANALYSIS AND EXAMPLE CALCULATIONS OF VE TRAINING PROGRAM ERRORS

Several elements of the VE training program performance can be estimated, within statistical limits, through error analysis of individual program activities. These error estimates may be combined to produce an aggregate error estimate. The probability limits resulting from this error estimate serve as a quantitative measure of program effectiveness and should be included as part of its documentation. Individual errors associated with the standardized calibration filters, the transmissometer as compared with these standardized filters, and the announced opacity as read from the transmissometer are determined along with their respective standard deviations (SD). Combined precision and accuracy can then be estimated for the transmissometer and smoke generator operator as well as the total precision and accuracy for the VE training program including trainee precision. The following sections provide example calculations and an error analysis for a VE training program. The descriptions of the statistics are not included since they are available in several standard statistical textbooks.

### Filter Quality Error

In order to determine the precision and accuracy of the transmissometer, the error associated with the standardized filters used to calibrate the transmissometer must be determined. The following assumption should be used to calculate filter quality error directly from the specifications of the standardized calibration filters.

1. Each NBS-traceable filter used to calibrate the transmissometer is accurate within ±0.5 percent opacity of its nominal value.
2. The area within 3 SD of the mean of a standard normal curve is 99.73 percent of the total area or approximately the total area.

3. Therefore, under the assumption of normal distribution of errors, the calibration filter standard error ($SD_1$) will be less than one-third of the nominal error or

$$SD_1 < \frac{0.5\%}{3}$$

$$SD_1 < 0.17\% \ .$$

The standard deviation of error associated with the calibration filters is therefore less than 0.17 percent opacity.

Linearity - Calibration Error

To determine how accurately the transmissometer compares with the standardized filters, the standard deviation ($SD_2$) of the transmissometer must be obtained by use of the following procedure. Note: At least 10 data points from each filter must be used.

1. Use the data obtained from filter readings taken during the VE program certification runs. Fifteen filter readings must be taken at the beginning of the training course, and 15 additional readings must be taken at the end. Record these data points on a form similar to that illustrated in Figure C-1.
2. Determine the difference ($d_i$) between each of the 30 values reported by the transmissometer and the actual opacities of the corresponding filters as shown in Figure C-1.
3. Sum the differences obtained in step 2 and determine the mean ($\bar{X}_2$) and the standard deviation ($SD_2$) of the 30 differences, where $d_1$ is the first difference, $d_2$ is the second, and so on.

$$\bar{X}_2 = \frac{d_1 + d_2 + d_3 + \ldots + d_{30}}{30} = \frac{\Sigma d_i}{n}$$

$$SD_2 = \left[\frac{(\Sigma d_i^{\,2}) - (\Sigma d_i)^2/n}{n - 1}\right]^{\frac{1}{2}}$$

Operational Error

The following procedure should be used to determine the standard deviation ($SD_3$) of the reporting error from the transmissometer, the difference between

| | INITIAL FILTER READINGS[a] | | | | FINAL FILTER READINGS[a] | | |
|---|---|---|---|---|---|---|---|
| | Measured | Actual | $d_i$ | | Measured | Actual | $d_i$ |
| 1 | 17.5 | 18 | -.5 | 16 | 17 | 18 | -1 |
| 2 | 17.5 | 18 | -.5 | 17 | 20 | 18 | +2 |
| 3 | 17.5 | 18 | -.5 | 18 | 17.5 | 18 | -.5 |
| 4 | 17.5 | 18 | -.5 | 19 | 19 | 18 | +1 |
| 5 | 17.0 | 18 | -1 | 20 | 18 | 18 | 0 |
| 6 | 49.0 | 50 | -1 | 21 | 50 | 50 | 0 |
| 7 | 49.5 | 50 | -.5 | 22 | 49.5 | 50 | -.5 |
| 8 | 49.5 | 50 | -.5 | 23 | 51 | 50 | +1 |
| 9 | 51 | 50 | +1 | 24 | 49 | 50 | -1 |
| 10 | 49.5 | 50 | -.5 | 25 | 50 | 50 | 0 |
| 11 | 76 | 74 | +2 | 26 | 75 | 74 | +1 |
| 12 | 74 | 74 | 0 | 27 | 74.5 | 74 | +.5 |
| 13 | 74.5 | 74 | +.5 | 28 | 74 | 74 | 0 |
| 14 | 74 | 74 | 0 | 29 | 73.5 | 74 | -.5 |
| 15 | 74 | 74 | 0 | 30 | 74 | 74 | 0 |

[a] Measured denotes values read by the transmissometer; actual denotes filter values; $d_i$ denotes the difference (Measured - Actual).

$$n = 30$$

$$\Sigma(d_i)^2 = 19$$

$$\overline{X}_2 = \frac{\Sigma d_i}{n} = \frac{0}{30} = 0$$

$$SD_2 = \left[\frac{\Sigma d_i{}^2 - (\Sigma d_i)^2/n}{n - 1}\right]^{\frac{1}{2}}$$

$$= \left[\frac{19 - (0^2/30)}{29}\right]^{\frac{1}{2}} = 0.80\%$$

Figure C-1. Linearity - calibration error data and calculations.

the actual opacity value as recorded on the transmissometer strip chart and the opacity as announced to the nearest 5 percent value by the generator operator.

1. Randomly select one certification run from the school's field training program. Note: Avoid selecting the first run--it usually will have the highest error, since the generator operator is unfamiliar with the generator's operation at this point. On a form similar to the one illustrated in Figure C-2, record the actual transmissometer readings for each of the 25 white smoke readings, the 25 readings as announced by the generator operator, and the calculated difference ($d_i$) for each of the readings.
2. Sum the differences obtained in step 1 and calculate the mean ($\bar{X}_3$) and standard deviation ($SD_3$) of the 25 readings, where $d_1$ is the first difference, $d_2$ is the second, etc.:

$$\bar{X}_3 = \frac{d_1 + d_2 + d_3 + \ldots + d_{25}}{25} = \frac{\Sigma d_i}{25}$$

$$SD_3 = \left[\frac{\Sigma d_i^{\,2} - (\Sigma d_i)^2/n}{n - 1}\right]^{\frac{1}{2}}$$

3. Repeat steps 1 and 2 for the 25 black smoke readings. Refer to Figure C-2 and the strip chart record trace illustrated in Figure C-3.

## Probability Limits

The following procedure is used to calculate the 95 percent probability limits (PL) for the actual readings. This calculation establishes a reasonable estimate of the combined transmissometer and generator operator error in reporting individual smoke readings (see Figure C-4). Figures C-1 and C-2 show the standard errors computed from the previous discussions of filter quality, linearity-calibration error, and operational error. The following steps outline the procedure for determining these probability limits.

Run #1

| WHITE SMOKE | | | BLACK SMOKE | | |
|---|---|---|---|---|---|
| Reported | Actual | $d_i$ | Reported | Actual | $d_i$ |
| 20 | 21 | -1 | 35 | 35 | 0 |
| 15 | 15.5 | -.5 | 35 | 34 | +1 |
| 10 | 9 | +1 | 25 | 26 | -1 |
| 10 | 10 | 0 | 15 | 15.5 | -.5 |
| 5 | 5.5 | -.5 | 10 | 10 | 0 |
| 10 | 10.5 | -.5 | 15 | 15.5 | -.5 |
| 15 | 14 | +1 | 20 | 20 | 0 |
| 20 | 19 | +1 | 40 | 41 | -1 |
| 35 | 35 | 0 | 40 | 39 | +1 |
| 30 | 29.5 | +.5 | 45 | 45 | 0 |
| 45 | 46 | -1 | 45 | 45.5 | -.5 |
| 50 | 50 | 0 | 55 | 54 | +1 |
| 50 | 49 | +1 | 65 | 65 | 0 |
| 70 | 70.5 | -.5 | 70 | 71 | -1 |
| 60 | 59.5 | +.5 | 75 | 74.5 | +.5 |
| 30 | 30 | 0 | 80 | 80 | 0 |
| 30 | 29 | +1 | 50 | 49 | +1 |
| 25 | 25 | 0 | 55 | 54.5 | +.5 |
| 20 | 19 | +1 | 40 | 40 | 0 |
| 20 | 21 | -1 | 25 | 24 | +1 |
| 10 | 10 | 0 | 15 | 16 | -1 |
| 30 | 30 | 0 | 10 | 9.5 | +.5 |
| 50 | 49 | +1 | 20 | 20 | 0 |
| 65 | 64.5 | +.5 | 30 | 29 | +1 |
| 5 | 6 | -1 | 35 | 35 | 0 |

For White Smoke:

$n = 25$

$\Sigma d_i = 2.5$

$\bar{X}_3 = \frac{\Sigma d_i}{n} = \frac{2.5}{25} = 0.1\%$

$\Sigma d_i^2 = 12.75$

$SD_3 = \left[\frac{12.75 - (2.5^2/25)}{24}\right]^{1/2} = 0.72\%$

For Black Smoke:

$n = 25$

$\Sigma d_i = 2.0$

$\bar{X}_3 = \frac{\Sigma d_i}{n} = \frac{2.0}{25} = 0.08\%$

$\Sigma d_i^2 = 11.50$

$SD_3 = \left[\frac{11.50 - (2.0^2/25)}{24}\right]^{1/2} = 0.69\%$

Figure C-2. Example of operational error data and calculation.

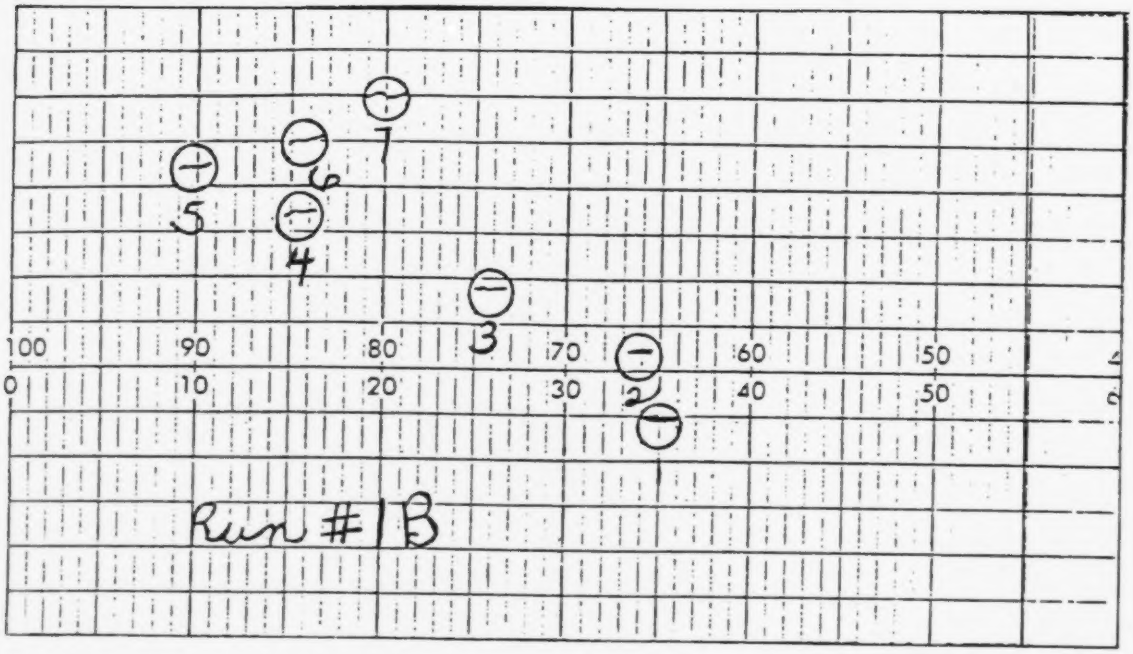


Figure C-3. Example of a strip chart recorder trace showing recorded opacity value.

For White Smoke:

$$\overline{X}_4 = \overline{X}_2 + \overline{X}_3$$

$$0.1 = 0 + 0.1$$

$$SD_4 = \left[(SD_1)^2 + (SD_2)^2 + (SD_3)^2\right]^{\frac{1}{2}}$$

$$1.00 = \left[(0.17)^2 + (0.81)^2 + (0.72)^2\right]^{\frac{1}{2}}$$

$$PL_4 = \overline{X}_4 \pm 2\ (SD_4) \text{ or}$$

$$PL_4 = 0.1 \pm 2\ (1.10) \text{ or}$$

$$0.1 + 2.20 = 2.3$$

$$0.1 - 2.20 = -2.1$$

For Black Smoke:

$$\overline{X}_4 = \overline{X}_2 + \overline{X}_3$$

$$0.08 = 0 + 0.08$$

$$SD_4 = \left[(SD_1)^2 + (SD_2)^2 + (SD_3)^2\right]^{\frac{1}{2}}$$

$$1.08 = \left[(0.17)^2 + (0.81)^2 + (0.69)^2\right]^{\frac{1}{2}}$$

$$PL_4 = \overline{X}_4 \pm 2\ (SD_4) \text{ or}$$

$$PL_4 = 0.08 \pm 2\ (1.08) \text{ or}$$

$$0.08 + 2.16 = 2.2$$

$$0.08 - 2.16 = -2.1$$

Therefore, 95% of the time it is expected that:

1. An individual white smoke reading will not exceed the true value by more than 2.3% opacity.

2. An individual white smoke reading will not be less than 2.1% opacity below the true value.

3. An individual black smoke reading will not exceed the true value by more than 2.2% opacity.

4. An individual black smoke reading will not be less than 2.1% opacity below the true value.

Calculated by ______________________________ Date ______________

Calculations Audited by ______________________ Date ______________

Figure C-4. Example calculations and reporting of probability limits for individual smoke readings.

1. Determine the mean error ($\bar{X}_4$) for white smoke.

$$\bar{X}_4 = \bar{X}_2 + \bar{X}_3$$

where $\bar{X}_2$ = mean of the 30 differences ($d_i$) from initial and final calibration error checks using NBS traceable filters

$\bar{X}_3$ = mean of the differences ($d_i$) from one certification run for 25 smoke readings for the operational error

2. Determine the cumulative standard deviation ($SD_4$) for white smoke.

$$SD_4 = \sqrt{(SD_1)^2 + (SD_2)^2 + (SD_3)^2}$$

where $SD_1$ = standard deviation of error of the standardized calibration filters, i.e., 0.17

$SD_2$ = standard deviation of the 30 differences ($d_i$) from initial and final calibration error checks using NBS traceable filters

$SD_3$ = standard deviation of the 25 differences ($d_i$) from one certification run for smoke readings for the operational error

3. Using the results from Steps 1 and 2, compute the 95 percent probability limits for individual white smoke readings.

$$PL_4 = \bar{X}_4 \pm 2(SD_4)$$

This results in a 95 percent probability that:

- An individual smoke reading will not exceed the true value by more than ____% opacity.
- An individual smoke reading will not be less than ____% opacity.

4. Repeat Steps 1, 2, and 3 for black smoke. Be sure to clearly mark whether the calculations are for white or black smoke. Sign and date the calculation form. It is recommended that the calculations be audited and that the auditor also sign and date the form as shown in Figure C-4.

## Aggregate Data Analysis

Even though the section on probability limits provides statistical calculations for generator operator's biases along with other sources of error, additional calculations are still required to derive a "total" cumulative error for the VE training program. The standard deviation ($SD_5$) of the difference between the actual opacity values and those recorded by the trainees measures the precision of the individual trainees.

Figure C-5 illustrates a qualifying test form. The procedures for calculating the mean ($\bar{X}_5$) and standard deviation ($SD_5$) for white smoke follow. Example calculations are illustrated in Figure C-6.

1. For each of the 25 white smoke readings on the qualifying test form record the opacity announced by the generator operator to the nearest 5 percent, the reported opacity from the trainee's test form, and the difference ($d_i$) between the announced and the trainee's values.
2. Sum all the differences obtained in step 1 and calculate the mean ($\bar{X}_5$) and the standard deviation ($SD_5$) of the 25 differences, where $d_1$ is the first difference, $d_2$ is the second, etc.

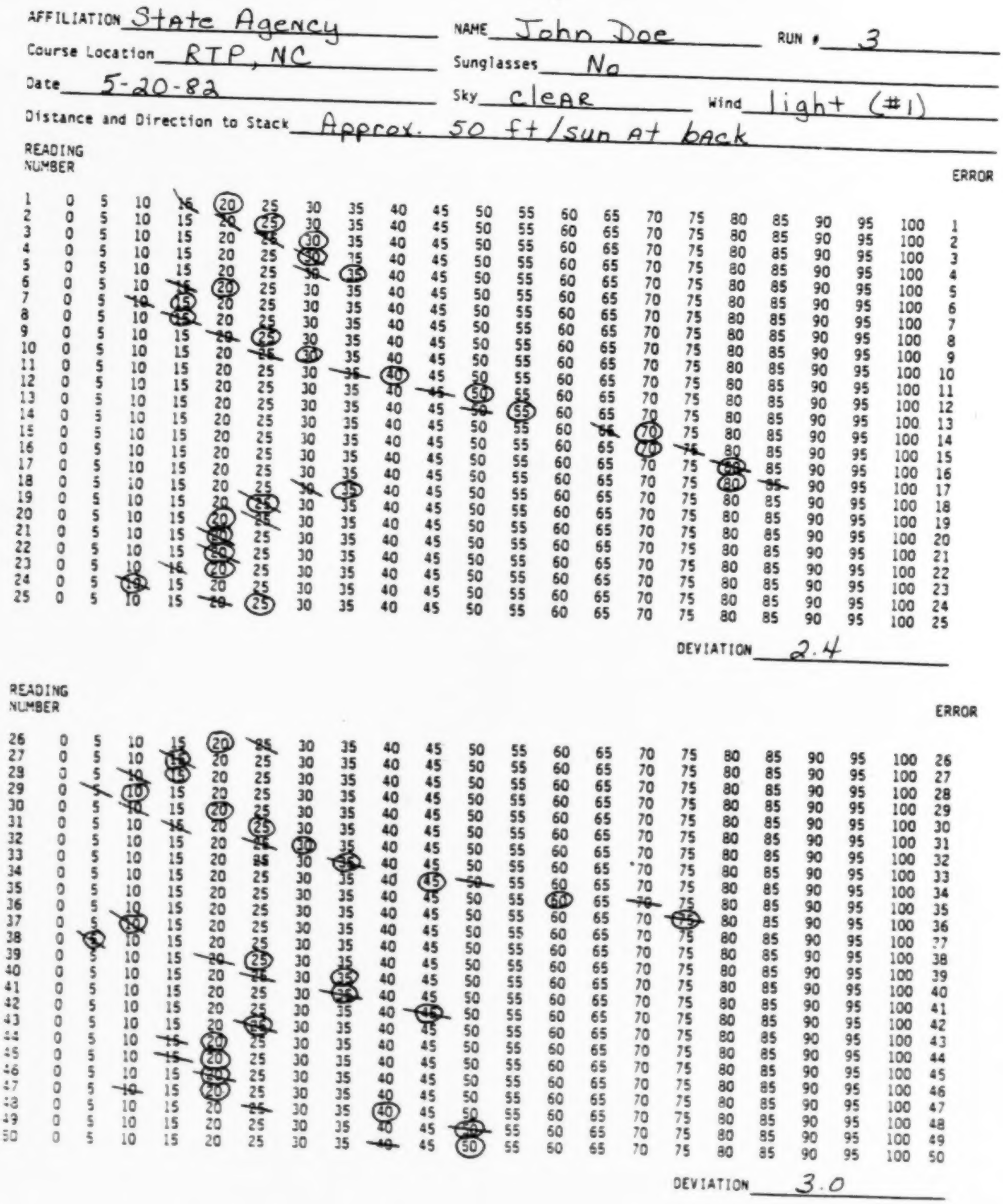
$$\bar{X}_5 = \frac{d_1 + d_2 + d_3 + \ldots + d_{25}}{25} = \frac{\Sigma d_i}{n}$$

$$SD_5 = \left[\frac{(\Sigma d_i^2) - (\Sigma d_i)^2/n}{n - 1}\right]^{\frac{1}{2}}$$

3. Repeat steps 1 and 2 for the 25 black smoke readings. Again, be sure to indicate which set of calculations is for white smoke and which is for black.

The following calculations establish a 95 percent confidence interval (CI) for the "true average" opacity based on 25 readings each of both white and black smoke by an individual.

1. Combine the three means for white smoke ($\bar{X}_5$) to calculate the mean error. See Figures C-6 and C-7.



AFFILIATION State Agency NAME John Doe RUN # 3

Course Location RTP, NC Sunglasses No

Date 5-20-82 Sky clear Wind light (#1)

Distance and Direction to Stack Approx. 50 ft/sun at back

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 5 | 10 | ~~15~~ | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 1 |
| 2 | 0 | 5 | 10 | 15 | ~~20~~ | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 2 |
| 3 | 0 | 5 | 10 | 15 | 20 | ~~25~~ | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 3 |
| 4 | 0 | 5 | 10 | 15 | 20 | 25 | [✓ ~~30~~] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 4 |
| 5 | 0 | 5 | 10 | 15 | 20 | 25 | ~~30~~ | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 5 |
| 6 | 0 | 5 | 10 | ~~15~~ | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 6 |
| 7 | 0 | 5 | ~~10~~ | [✓ 15] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 7 |
| 8 | 0 | 5 | 10 | [✓ ~~15~~] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 8 |
| 9 | 0 | 5 | 10 | 15 | ~~20~~ | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 9 |
| 10 | 0 | 5 | 10 | 15 | 20 | ~~25~~ | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 10 |
| 11 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | ~~35~~ | [✓ 40] | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 11 |
| 12 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | ~~45~~ | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 12 |
| 13 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | ~~50~~ | [✓ 55] | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 13 |
| 14 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | ~~65~~ | [✓ 70] | 75 | 80 | 85 | 90 | 95 | 100 | 14 |
| 15 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | [✓ 70] | ~~75~~ | 80 | 85 | 90 | 95 | 100 | 15 |
| 16 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | [✓ ~~80~~] | 85 | 90 | 95 | 100 | 16 |
| 17 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | [✓ 80] | ~~85~~ | 90 | 95 | 100 | 17 |
| 18 | 0 | 5 | 10 | 15 | 20 | 25 | ~~30~~ | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 18 |
| 19 | 0 | 5 | 10 | 15 | 20 | [✓ ~~25~~] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 19 |
| 20 | 0 | 5 | 10 | 15 | [✓ 20] | ~~25~~ | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 20 |
| 21 | 0 | 5 | 10 | 15 | [✓ ~~20~~] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 21 |
| 22 | 0 | 5 | 10 | 15 | [✓ ~~20~~] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 22 |
| 23 | 0 | 5 | 10 | ~~15~~ | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 23 |
| 24 | 0 | 5 | [✓ ~~10~~] | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 24 |
| 25 | 0 | 5 | 10 | 15 | ~~20~~ | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 25 |

DEVIATION 2.4

| READING NUMBER | | | | | | | | | | | | | | | | | | | | | | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 0 | 5 | 10 | 15 | [✓ 20] | ~~25~~ | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 26 |
| 27 | 0 | 5 | 10 | [✓ ~~15~~] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 27 |
| 28 | 0 | 5 | ~~10~~ | [✓ 15] | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 28 |
| 29 | 0 | ~~5~~ | [✓ 10] | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 29 |
| 30 | 0 | 5 | ~~10~~ | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 30 |
| 31 | 0 | 5 | 10 | ~~15~~ | 20 | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 31 |
| 32 | 0 | 5 | 10 | 15 | 20 | ~~25~~ | [✓ 30] | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 32 |
| 33 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ ~~35~~] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 33 |
| 34 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ 45] | ~~50~~ | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 34 |
| 35 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | [✓ 60] | 65 | ~~70~~ | 75 | 80 | 85 | 90 | 95 | 100 | 35 |
| 36 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | [✓ ~~75~~] | 80 | 85 | 90 | 95 | 100 | 36 |
| 37 | 0 | 5 | [✓ ~~10~~] | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 37 |
| 38 | 0 | [✓ ~~5~~] | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 38 |
| 39 | 0 | 5 | 10 | 15 | ~~20~~ | [✓ 25] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 39 |
| 40 | 0 | 5 | 10 | 15 | 20 | ~~25~~ | 30 | [✓ 35] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 40 |
| 41 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | [✓ ~~35~~] | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 41 |
| 42 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | [✓ ~~45~~] | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 42 |
| 43 | 0 | 5 | 10 | 15 | 20 | [✓ ~~25~~] | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 43 |
| 44 | 0 | 5 | 10 | ~~15~~ | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 44 |
| 45 | 0 | 5 | 10 | ~~15~~ | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 45 |
| 46 | 0 | 5 | 10 | 15 | [✓ ~~20~~] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 46 |
| 47 | 0 | 5 | ~~10~~ | 15 | [✓ 20] | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 47 |
| 48 | 0 | 5 | 10 | 15 | 20 | ~~25~~ | 30 | 35 | [✓ 40] | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 48 |
| 49 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | [✓ ~~50~~] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 49 |
| 50 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | ~~40~~ | 45 | [✓ 50] | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 50 |

DEVIATION 3.0

Figure C-5. Example of a qualifying opacity test form.

AFFILIATION____________ NAME____________ RUN____________
COURSE LOCATION____________ SUNGLASSES____________
DATE____________ SKY____________ WIND____________
DISTANCE AND DIRECTION TO STACK____________

| Reading | WHITE SMOKE |  |  | BLACK SMOKE |  |  |  |
|---|---|---|---|---|---|---|---|
|  | Reported | Actual | $d_i$ | Reading | Reported | Actual | $d_i$ |
| 26 | 20 | 25 | -5 | 1 | 20 | 15 | +5 |
| 27 | 15 | 15 | 0 | 2 | 25 | 20 | +5 |
| 28 | 15 | 10 | +5 | 3 | 30 | 25 | +5 |
| 29 | 10 | 5 | +5 | 4 | 30 | 30 | 0 |
| 30 | 20 | 10 | +10 | 5 | 35 | 30 | +5 |
| 31 | 25 | 15 | +10 | 6 | 20 | 15 | +5 |
| 32 | 30 | 25 | +5 | 7 | 15 | 10 | +5 |
| 33 | 35 | 35 | 0 | 8 | 15 | 15 | 0 |
| 34 | 45 | 50 | -5 | 9 | 25 | 20 | +5 |
| 35 | 60 | 70 | -10 | 10 | 30 | 25 | +5 |
| 36 | 75 | 75 | 0 | 11 | 40 | 35 | +5 |
| 37 | 10 | 10 | 0 | 12 | 50 | 45 | +5 |
| 38 | 5 | 5 | 0 | 13 | 55 | 50 | +5 |
| 39 | 25 | 20 | +5 | 14 | 70 | 65 | +5 |
| 40 | 35 | 25 | +10 | 15 | 70 | 75 | -5 |
| 41 | 35 | 35 | 0 | 16 | 80 | 80 | 0 |
| 42 | 45 | 45 | 0 | 17 | 80 | 85 | -5 |
| 43 | 25 | 25 | 0 | 18 | 35 | 30 | +5 |
| 44 | 20 | 15 | +5 | 19 | 25 | 25 | 0 |
| 45 | 20 | 15 | +5 | 20 | 20 | 25 | -5 |
| 46 | 20 | 20 | 0 | 21 | 20 | 20 | 0 |
| 47 | 20 | 10 | +10 | 22 | 20 | 20 | 0 |
| 48 | 40 | 25 | +15 | 23 | 20 | 15 | +5 |
| 49 | 50 | 50 | 0 | 24 | 10 | 10 | 0 |
| 50 | 50 | 40 | +10 | 25 | 25 | 20 | +5 |

For White Smoke:

$n = 25$

$\bar{X}_5 = \frac{\Sigma d_i}{n} = \frac{75}{25} = 3.0$

$\Sigma d_i^2 = 1025$

$$SD_5 = \left[\frac{1025 - (75^2/25)}{24}\right]^{\frac{1}{2}} = 5.77$$

For Black Smoke:

$n = 25$

$\bar{X}_5 = \frac{\Sigma d_i}{n} = \frac{60}{25} = 2.4$

$\Sigma d_i^2 = 450$

$$SD_5 = \left[\frac{450 - (60^2/25)}{24}\right]^{\frac{1}{2}} = 3.57$$

Figure C-6. Example data and calculations for determining student certification.

For White Smoke:

$$\overline{X}_6 = (\overline{X}_2) + (\overline{X}_3) + (\overline{X}_5)$$

$$3.1 = 0 + 0.1 + 3.0$$

$$SD_6 = \left[(SD_1)^2 + (SD_2)^2 + (SD_3)^2 + (SD_5)^2\right]^{\frac{1}{2}}$$

$$5.87 = \left[(.17)^2 + (.81)^2 + (.722)^2 + (5.77)^2\right]^{\frac{1}{2}}$$

$$CI_6 = \overline{X}_6 \pm \frac{2(SD_6)}{\sqrt{25}} \text{ or } \frac{2(5.87)}{\sqrt{25}}$$

$$CI_6 = 3.1 \pm \frac{2(5.87)}{\sqrt{25}}$$

$$3.1 + 2.35 = 5.5$$

$$3.1 - 2.35 = 0.8$$

For Black Smoke:

$$\overline{X}_6 = (\overline{X}_2) + (\overline{X}_3) + (\overline{X}_5)$$

$$2.48 = 0 + 0.08 + 2.4$$

$$SD_6 = \left[(SD_1)^2 + (SD_2)^2 + (SD_3)^2 + (SD_5)^2\right]^{\frac{1}{2}}$$

$$3.72 = \left[(.17)^2 + (.81)^2 + (.69)^2 + (3.57)^2\right]^{\frac{1}{2}}$$

$$CI_6 = \overline{X}_6 \pm \frac{2(SD_6)}{\sqrt{25}} \text{ or } \frac{2(3.73)}{\sqrt{25}}$$

$$CI_6 = 2.48 \pm \frac{2(3.73)}{\sqrt{25}}$$

$$2.48 + 1.49 = 4.0$$

$$2.48 - 1.49 = 1.0$$

Therefore, 95% of the time it is expected that:

White Smoke

1. (Qualified Individual's Name) will not report an average of 25 white smoke readings in excess of 5.5% opacity above the true opacity.
2. (Qualified Individual's Name) will not report an average of 25 white smoke readings below 0.8% opacity above the true opacity.

Black Smoke

1. (Qualified Individual's Name) will not report an average of 25 black smoke readings in excess of 4.0% opacity above the true opacity.
2. (Qualified Individual's Name) will not report an average of 25 black smoke readings below 1.0% opacity above the true opacity.

Calculated by ______________________________ Date ____________

Calculations Checked by ______________________________ Date ____________

Figure C-7. Example calculations for determining the bias and confidence intervals for a true average opacity reading by an individual observer.

$$\bar{X}_6 = \bar{X}_2 + \bar{X}_3 + \bar{X}_5$$

where $\bar{X}_2$ = mean of the 30 differences ($d_i$) from initial and final calibration error checks using NBS traceble filters

$\bar{X}_3$ = mean of the 25 differences ($d_i$) from one certification run for white smoke readings for the operational error

$\bar{X}_5$ = mean of the 25 differences ($d_i$) from the trainee's test form for white smoke readings

2. Combine the four standard deviations for white smoke to obtain the "total" cumulative standard deviation ($SD_6$) as illustrated in Figure C-7.

$$SD_6 = \sqrt{(SD_1)^2 + (SD_2)^2 + (SD_3)^2 + (SD_5)^2}$$

where $SD_1$ = standard deviation of error in standardized calibration filters

$SD_2$ = standard deviation of the 30 differences ($d_i$) from initial and final calibration error checks using NBS traceable filters

$SD_3$ = standard deviation of the 25 differences ($d_i$) from one certification run for white smoke readings for the operational error

$SD_5$ = standard deviation of the 25 differences ($d_i$) for white smoke readings recorded on the trainee test form and the master sheet for the operator's announced transmissometer readings

3. Compute an approximate 95 percent confidence interval for "true average" opacity based on white smoke readings.

$$CI_6 = \bar{X}_6 \pm \frac{2SD_6}{\sqrt{n}}$$

where $CI_6$ = 95 percent confidence interval for white smoke

$\bar{X}_6$ = average of three means for the error for white smoke

$SD_6$ = pooled or combined average of four standard deviations for white smoke

$\sqrt{n}$ = square root of the number of white smoke readings

4. Using the results computed from Step 3, record the 95 percent confidence interval on a form similar to the one illustrated in Figure C-7.
5. Repeat steps 1 through 4 for the black smoke readings. Be sure to clearly indicate whether the calculations are for white or black smoke.
6. Sign and date the calculation form. It is recommended that the calculations be audited and that the auditor also sign and date the form.